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TIMBER GROWING AND LOGGING PRACTICE IN THE SOUTHWEST AND IN THE BLACK HILLS REGION

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INTRODUCTION

Timber culture, like the growing of farm crops, is necessarily governed in any country by the soil and climate, by the requirements of native forest trees, and by local economic circumstances. Lessons may be drawn from the experience of other countries, as the United States has drawn upon the forestry of Europe; but profitable methods of growing timber, particularly under the wide range of forest types and economic conditions in the United States, can be worked out only from actual experience and investigation, region by region. Hence, to meet the need for information on practical ways and means of growing timber profitably in the various parts of the United States, it is important that the results of these experiences and investigations to date be brought together and set forth in the

[1] The Southwestern Forest and Range Experiment Station is maintained in cooperation with the University of Arizona.

[2] The authors wish to acknowledge the cooperation of various members of the Forest Service and of other bureaus in the Department of Agriculture in preparing this bulletin. Valuable assistance has been rendered particularly by Quincy Randles, M. W. Thompson, and C. B. Morse. These and other members of the Forest Service have read the manuscript and have offered constructive suggestions. The information on insects, wild animal life, and diseases has been obtained largely from the Division of Forest Insects of the Bureau of Entomology and Plant Quarantine, the Bureau of Biological Survey, and the Division of Forest Pathology of the Bureau of Plant Industry.

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clearest possible way. The value of timber, with other economic considerations, is causing landowners more and more widely to study the possibility of profitable reforestation. These developments have created a general demand for information on the timber-growing methods adapted to the various types of forest growth in the United States and what these methods will cost.

The Forest Service has attempted to meet this demand in a series of publications dealing with 12 of the principal forest regions of the United States, of which the first was issued in 1926. The information presented has been gathered from many different sources, including the experience of landowners who have engaged in reforestation. An effort has been made to bring together the gist of what has thus far been learned about the growing of timber in the United States; and the results have been verified as far as possible by consultation with the forest industries, State foresters, and forest schools. This bulletin thus undertakes to set forth what are believed to be the soundest methods of reforestation as yet developed in common experience and study in the Southwest and Black Hills regions.

Various factors enter into the forestry problem in the Southwest to make its solution distinct from that for any other region. For one thing, only a small percentage of the land area in the region covered by this bulletin—and that only in the rougher country and at the higher elevations—is timbered. Nevertheless, these timbered areas are of first importance to the whole region, since they are located at the headwaters of the principal streams, and these, in turn, supply water for irrigation without which farming in the lower valleys would be impossible. Therefore, the effect of forests on stream flow is in this region a consideration paramount to that of any other forest use. But, aside from their watershed value, these forests are of more than ordinary economic value to the region as a source of wood for local use. This timbered area is surrounded by very extensive areas of nontimbered land both in New Mexico and Arizona and in the Great Plains; these open grazing and farm lands constitute an excellent market for locally grown timber.

On the other hand, adverse climatic conditions in the region are reflected in light timber stands of relatively slow growth. While the practices recommended herein for the production of full timber crops give every promise of resulting in heavier yields than would be expected from estimates based on present stands, the indications are that timber growing as a private industry will not be financially profitable under average conditions. Fortunately, a relatively large percentage of the timbered land is already in the hands of public agencies, and on these lands the practice of intensive forestry methods may be expected to go substantially farther than at present toward supplying local needs for timber, at the same time that the greatest possible protection is given to water supplies. Meanwhile, private lands are being cut over, and the fact that the most intensive forestry may be impracticable under private ownership does not lessen the prime necessity for their protection from devastation. The requirements here outlined as "minimum measures to keep forest lands productive" represent the lowest standards of practice that will assure keeping privately owned lands in such condition that, under subsequent public management, they can yield satisfactory timber crops without the almost prohibitive expense of planting.

Much of the timberland in the region supports a forage crop in addition to the timber. The proper utilization of this forage crop will return a revenue and at the same time will not be detrimental to the timber crop. Improper utilization of the forage crop has been found to be destructive to both forage and timber. Protection, therefore, takes a somewhat broader meaning than in some other regions where forage utilization is not so large a factor.

THE REGION

GEOGRAPHY AND PHYSIOGRAPHY

The territory covered by this bulletin comprises all of the forest area of New Mexico and Arizona, a strip along the southern edge of Colorado and Utah, and the Black Hills of South Dakota and Wyoming.

The designation "Southwest" is applied to the forested lands of Arizona, New Mexico, southern Colorado, and Utah, which fall into three fairly well-defined subregions (fig. 1). In the northern part are the high southern Rockies, which include the extensive mountain forests of northern New Mexico and southern Colorado, as well as several smaller areas in southern Utah. Across central Arizona and New Mexico lies the extensive, timbered Colorado Plateau which, speaking geographically rather than geologically, extends from southern Utah southward across the Grand Canyon to the Mogollon Rim, and eastward in New Mexico, taking in the Cibola (formerly Manzano) and Gila National Forests. Farther south is what may be called the border—the desert dotted with isolated peaks and ranges, the highest of which are forest clad. Prominent among these are the Sacramentos, the Chiricahuas, the Santa Catalinas, and Mount Graham. Many relatively small forest areas are found on these numerous disconnected mountain masses.

Two great rivers—the Rio Grande and the Colorado—pass through and drain the greater part of the Southwest. These rise in the mountains farther north, but pick up many important tributaries which have their sources in the mountains to the south. Wide extremes of altitude are encountered with corresponding climatic variation ranging from a few feet above sea level at Yuma to the crest of the Rocky Mountains at nearly 14,000 feet. As it descends from the higher mountains and plateaus, the forest cover gives way to less luxuriant forms of vegetation. At the lower limits, as in the Salt River Valley and in the Colorado River Valley at Yuma, climate and soil are suitable for growing citrus and other subtropical crops on irrigated land.

The Black Hills of South Dakota and Wyoming form an isolated mountain region of a generally lower elevation than the forest areas of the Southwest. It is characterized by forest-covered slopes and numerous permanent streams whose narrow valleys are well adapted to farming. The Black Hills is the source of many of the tributaries of the Cheyenne, itself an important branch of the Missouri River.

FORESTS

The saw-timber forests divide themselves readily into three distinct types, or tree associations, named after the predominant species in each. These are the ponderosa pine (*Pinus ponderosa* Laws.) type, by far the most extensive and most important, the Douglas fir (*Pseudotsuga taxifolia* (LaM.) Britt.) type, and the Engelmann spruce (*Picea engelmannii* Engelm.) type. Tables 1 to 4 show the total estimated stand by area, volume, forest type, ownership, and subregion. The tables exclude areas on which the timber is too scattering or of too small size to warrant commercial logging operations under any reasonable market conditions. They also exclude areas

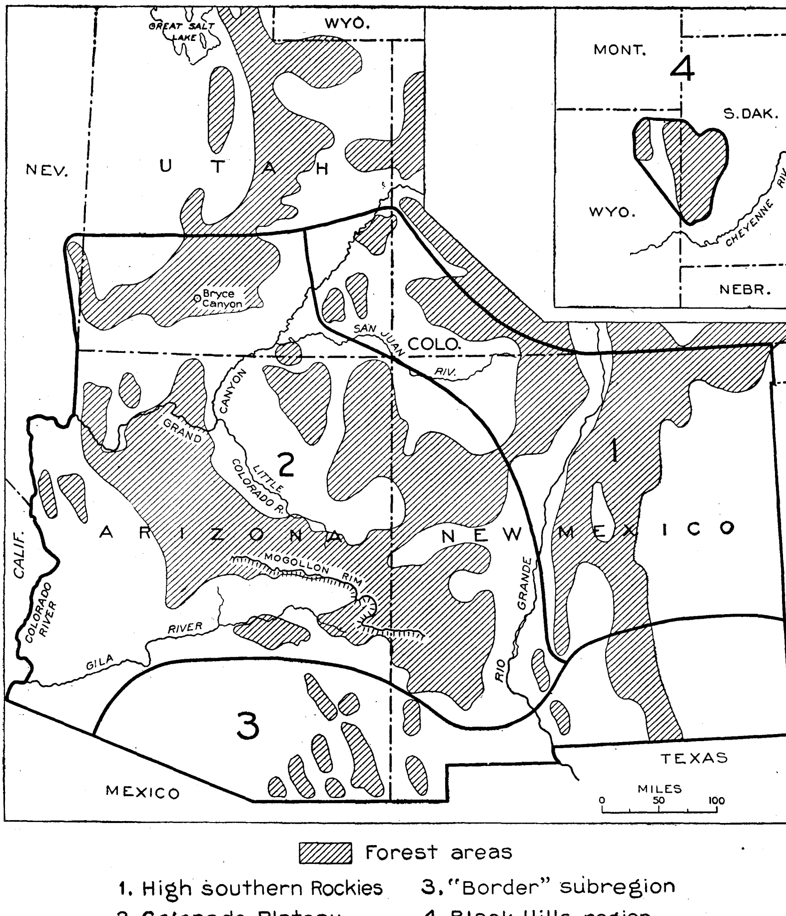

FIGURE 1.—Subregions comprising the southwestern and Black Hills forests.

regarded as inaccessible by present means of transportation, such as alpine stands and areas of very rough topography. According to these tables the total volume of commercial saw timber is nearly 42 billion board feet. The volume distribution by types is: Ponderosa pine, 84 percent; Douglas fir, 15 percent; Engelmann spruce, 1 percent. By class of ownership, the national forests contain 72 percent, Indian reservations and public domain 14 percent, States 2 percent, private 12 percent, or a total of 88 percent under public ownership. About 63 percent of the total volume is on the Colorado Plateau.

TABLE 1.—*Area and volume of saw timber in the Southwest by class of ownership and forest type*

AREA IN ACRES

Forest type and condition	National forests	Indian reservations	Other Federal	State	Private	Total
Ponderosa pine:						
Virgin	4, 214, 626	1, 362, 000	65, 000	115, 135	619, 181	6, 375, 942
Cut-over	1, 114, 753	142, 000	55, 900	39, 294	487, 269	1, 839, 216
Total	5, 329, 379	1, 504, 000	120, 900	154, 429	1, 106, 450	8, 215, 158
Fir-spruce:						
Virgin	983, 437	32, 000		23, 982	222, 039	1, 261, 458
Cut-over	123, 140	5, 000			67, 125	195, 265
Total	1, 106, 577	37, 000		23, 982	289, 164	1, 456, 723
All types:						
Virgin	5, 198, 063	1, 394, 000	65, 000	139, 117	841, 220	7, 637, 400
Cut-over	1, 237, 893	147, 000	55, 900	39, 294	554, 394	2, 034, 481
Total	6, 435, 956	1, 541, 000	120, 900	178, 411	1, 395, 614	9, 671, 881

VOLUME IN MILLION FEET BOARD MEASURE

Forest type and condition	National forests	Indian reservations	Other Federal	State	Private	Total
Ponderosa pine	25, 577	5, 562	12	537	3, 357	35, 045
Fir-spruce	4, 427	379		159	1, 568	6, 533
Total	30, 004	5, 941	12	696	4, 925	41, 578

TABLE 2.—*Area and volume of saw timber by subregion and forest type*

AREA IN ACRES

Forest type and condition	Colorado Plateau	Border	Southern Rockies	Black Hills	Total
Ponderosa pine:					
Virgin	3, 971, 196	663, 000	1, 169, 972	571, 774	6, 375, 942
Cut-over	795, 779	67, 000	494, 214	482, 223	1, 839, 216
Total	4, 766, 975	730, 000	1, 664, 186	1, 053, 997	8, 215, 158
Fir-spruce:					
Virgin	506, 212	110, 000	645, 246		1, 261, 458
Cut-over	52, 141	28, 000	115, 124		195, 265
Total	558, 353	138, 000	760, 370		1, 456, 723
All types:					
Virgin	4, 477, 408	773, 000	1, 815, 218	571, 774	7, 637, 400
Cut-over	847, 920	95, 000	609, 338	482, 223	2, 034, 481
Total	5, 325, 328	868, 000	2, 424, 556	1, 053, 997	9, 671, 881

VOLUME IN MILLION FEET BOARD MEASURE [1]

Forest type and condition	Colorado Plateau	Border	Southern Rockies	Black Hills	Total
Ponderosa pine	22, 769	1, 510	8, 341	2, 424	35, 044
Fir-spruce	3, 307	550	2, 677		6, 534
Total	26, 076	2, 060	11, 018	2, 424	41, 578

[1] Commercial saw timber on areas exclusive of those cut over.

TIMBER CUTTING

Six more or less distinct lumbering centers are recognized. These are northern Arizona, northern New Mexico, southern Colorado, the Zuni Mountains, the Sacramento Mountains, and the Black Hills.

Cutting commenced in northern Arizona, northern New Mexico, southern Colorado, and the Zuni Mountains about 1880; in the Sacramento Mountains about 1905; and in the Black Hills about 1875.

Reference to tables 1 and 2 shows that out of more than 9,500,000 acres of timberland, only 21 percent has been cut over. By classes of ownership, 40 percent of the private and only 19 percent of the national-forest land has been logged. In considering the apparently huge percentage yet available, it must be remembered that considerable areas are so located that the timber cannot be marketed until there is a substantial rise in stumpage prices. Although there are many local variations in conditions, the present management problem is largely one of handling virgin stands.

DEVASTATED AREAS

Forest devastation as here understood implies the removal of forest trees in such degree that natural restocking in the near future is virtually precluded. Areas denuded of commercial timber but bearing appreciable seedling growth or scattering young trees approaching seed-bearing age are not regarded as devastated. Cutting alone rarely results in devastation in this region because even the most extreme type of clear cutting nearly always leaves a few trees capable of bearing seed. It is only when cutting is followed by fire that conditions approaching devastation are created. Theoretically, any denuded forest land under protection should eventually restock to trees, because seeds carried long distances by wind, birds, and rodents will give rise to occasional seedlings which in the course of time will become seed trees. Whether or not such areas should be classed as devastated depends, from a practical viewpoint, upon the time required for restocking. In order to establish a uniform concept, the term "forest devastation" has been applied in this bulletin to areas on which natural reproduction sufficient to form a commercial stand of timber is not expected to take place within 100 years.

An estimate of the acreage classed as devastated in this region is given in table 3. Although a considerable portion of this acreage occurs in national forests, the devastation in nearly all instances took place before the national forests were created. Large areas which actually have been devastated will probably always be inaccessible for logging, and for this reason are not technically classed as devastated. Such areas, made up largely of spruce burns in the high mountains, have been excluded from table 3.

TABLE 3.—*Area of devastated land in acres by forest type and ownership*

Ownership	Ponderosa pine type	Fir-spruce type	All types
Federal:			
National forests [1]	77,845	14,000	91,845
Indian reservations	4,500		4,500
State	2,200	1,000	3,200
Private	89,200	32,000	121,200
Total	173,745	47,000	220,745

[1] Devastated almost uniformly before inclusion in national forests.

CONDITIONS AFFECTING THE PRACTICE OF FORESTRY

The primary basis for the formulation of measures necessary for effective forest production must be sound information regarding habits and requirements of different species of trees. A very important secondary consideration, however, is the degree of influence exerted by economic conditions and public sentiment, since these largely determine the extent to which the application of any proposed measure is practical. It is the purpose here to present a birdseye view of these factors as well as a discussion of silvical facts.

ECONOMIC CONSIDERATIONS

FOREST VALUES

The total annual consumption of forest products in Arizona and New Mexico prior to 1930 is estimated at 350,000,000 board feet. The lumber cut for 1928 was 320,000,000 board feet, whereas consumption was estimated at 190,000,000. Even so, local material does not control the market and meets severe competition from the Pacific coast and the southern pine belt. Lumber from other regions can compete even in the face of a freight charge averaging $14 per M as against an average of $5 on home products consumed locally. This situation forces producers in the Southwest to seek markets which offer a still greater advantage in freight rates.

In 1928 Arizona shipped forest products to 23 States, consuming locally approximately 26 percent of the cut. In the same year New Mexico shipped to 25 States, consuming locally approximately 37 percent.

It is not anticipated that this situation will continue indefinitely Eventually the competition from Northwest lumber will probably be less keen than at the present time. The needs for wood by a comparatively undeveloped region such as the Southwest should increase with growing population and industry. The opportunity for the employment of labor and capital in the growing, harvesting, manufacturing, and merchandising of the forest crop is of major importance to communities near the forests. These industries also contribute in taxes to the support of county and State governments. All these and other benefits of the forest argue strongly for the continuance of these lands in timber even though it must be accomplished through public ownership. It is estimated that if all productive forest lands in Arizona and New Mexico—regardless of ownership, and eliminating those which have been devastated or which are classed as inaccessible for lumbering—were placed under management such as is now practiced on the national forests, they might yield about 300 million board feet per year perpetually. Any appreciable increase over this production would require more intensive silviculture than is now being practiced. If such an increase becomes desirable, it can probably be obtained most economically by applying intensive methods on the best and most accessible lands.

More than 90 percent of the present and future agricultural development of the Southwest is dependent upon irrigation. The limitations of this development are directly dependent upon the amount of water permanently available. The flow of water from well-managed forest areas is for the most part clear and steady, in contrast with the erratic floods of silt-laden water from more or less denuded areas.

All the larger streams used for irrigation in this region have their headwaters in the forests. Watershed protection will be obtained automatically under good forest management.

Recreation is fast assuming a prominent place among the forest values in the Southwest. The ponderosa pine forests, in particular, delight the tourist with their open parklike spacing, the numerous secondary roads leading into out-of-the-way places, the exhilarating summer climate, and lastly, the absence of fires of such proportions as to endanger human life. Hunting and fishing attract thousands of people to the woods and are indirectly a considerable source of revenue to forest communities. Utilization of timber under good forest management is not incompatible with the preservation of recreational values.

The Black Hills is in many respects an economic unit. It is a region of forests, mines, and farms, a region comparatively rich in natural resources, surrounded for great distances by treeless plains used for little but stock raising and dry farming. It is reached by branch lines of the Chicago, Burlington & Quincy; Chicago & North Western; and Chicago, Minneapolis & St. Paul railroads. Mining is the principal industry. The Homestake Mine is the largest gold producer in the United States. The mines and railroads require a large amount of timber for stulls, ties, and lumber. The ranches and farms constitute a stable market for miscellaneous forest products. Although lumber from the "Inland Empire" and the Pacific coast competes with and helps to establish the price in the local market, it is economically much sounder that the bulk of the supply be obtained locally, and that the many small sawmilling communities be assured a permanent outlet for their products. It is probable that under good management a perpetual annual yield of at least 40,000,000 feet can be maintained in this region.

OVERHEAD EXPENSE IN LOGGING OPERATIONS

Except on small areas subject to peculiar local conditions, it is fair to say that large-scale commercial operations in virgin stands must have an average minimum cut of 5,000 board feet per acre to make operation economically practicable in any of the forest types in the Southwest. In some cases the cut runs considerably higher than this over the entire operating area. Even in the ponderosa pine type some of the very large lumbering operations count upon a cut of 9,000 to 10,000 board feet per acre and could scarcely operate if it were less. In the Douglas fir type the cut will run as high as 20,000 feet per acre, and one large concern operates in country where the cut has averaged over 18,000 feet for thousands of acres. In the Black Hills, in the pine type, the local market demands are possibly a little keener, and the situation in general is such that operation is practicable with a cut of 3,000 board feet per acre or even less.

An advance in lumber price levels would tend to increase the margin between cost of manufacture and selling price, thus permitting the higher overhead cost incident to a smaller cut per acre. It may be expected that as virgin-timber supplies decrease the selling price of good grades of lumber will increase. On the other hand, it is true that merchantable virgin stands are becoming less and less accessible, and that higher transportation costs will tend to increase production expense.

The market calls for two classes of products: (1) Lumber, and (2) ties, mine stulls, and props. The great bulk of the material goes into lumber. Trees less than 11 inches in diameter are too small to produce a standard hewn tie, but mine props are cut as short as 4 feet with a 4-inch top diameter.

RATE OF GROWTH

To produce saw logs, it is considered necessary in the Southwest to grow trees at least 20 inches d. b. h.[3] and in the Black Hills 16 inches d. b. h. Table 4 indicates that although ponderosa pine and Douglas fir may on the best sites attain a diameter of 20 inches in 100 years or even less, 140 to 180 years are required on most national forests in this region and in some instances 200 or more years. The figures in this table have not been definitely correlated as to site quality and density of stand, and for this reason are not to be regarded as a measure of differences between national forests. They do, however, give a fair indication of the range of diameter growth and the possibilities under the most favorable conditions. In the Black Hills, 16-inch trees can be grown in moderately dense stands in about 140 years. Under Forest Service methods of partial cutting it is planned in the Southwest to cut over the forest 2 or 3 times during a rotation;[4] in the Black Hills, 4 times. Without going into details as to volume yields, it is apparent that growth is generally slow and financial returns are meager in comparison with conditions in the best timber-growing regions in the United States.

TABLE 4.—*Diameter of southwestern species at different ages, in Arizona, New Mexico, and the Black Hills*

Species, national forest, and type or site	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years	180 years	200 years
Ponderosa pine:										
Apache:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Type 1[1]	2.0	4.6	7.4	9.9	12.2	14.4	16.5	18.1	19.7	------
Type 2[2]	1.3	3.4	6.0	9.0	12.0	14.8	17.5	20.0	22.4	24.7
Tusayan	1.8	5.2	8.4	11.1	13.2	15.0	16.6	18.0	19.3	20.4
Prescott	4.0	11.4	16.8	21.0	24.0	26.2	27.6	28.6	29.4	30.0
Sitgreaves	------	------	11.2	14.7	17.7	20.2	22.1	23.8	25.2	26.4
Gila	1.0	6.8	11.2	14.8	17.6	19.8	21.5	22.9	23.8	24.7
Crook	3.0	8.1	13.6	17.7	20.1	22.6	25.2	26.7	28.4	29.5
Carson	0.7	3.1	6.5	9.3	11.4	13.0	14.3	15.6	16.8	18.1
Harney:										
Site 1	3.0	5.6	7.5	8.8	9.9	11.2	12.6	13.9	15.2	16.2
Site 2	1.9	3.7	5.5	7.0	8.2	9.3	10.3	11.0	11.8	12.4
Site 3	1.5	2.9	4.2	5.6	6.7	7.6	8.4	9.0	9.5	9.9
Douglas fir:										
Apache	1.4	3.4	6.0	9.0	12.2	15.6	18.8	22.0	26.0	27.7
Crook	1.9	8.9	13.4	17.2	19.8	22.4	25.0	27.6	30.3	31.9
Gila	------	5.2	9.0	12.6	15.7	18.7	21.5	24.5	27.2	29.0
Carson	------	2.3	4.9	7.3	9.6	11.7	13.5	15.3	17.4	20.0
White fir:										
Crook	1.8	7.0	11.2	14.4	17.8	20.2	22.2	------	------	------
Carson	------	1.7	4.2	6.9	9.1	10.9	12.2	13.5	14.8	16.2
Limber pine:										
Crook	1.0	5.0	8.7	11.5	13.7	15.5	17.0	18.3	------	------
Blue spruce:										
Apache	1.1	3.8	9.2	14.8	18.4	21.0	22.8	------	------	------
Engelmann spruce:										
Crook	------	3.0	6.6	10.2	13.1	15.2	16.7	18.3	19.8	------
Carson	------	2.1	4.9	8.3	10.9	13.1	14.9	16.4	17.7	------
Alpine fir:										
Carson	------	2.0	4.9	8.3	10.8	12.8	14.2	16.4	17.1	------

1 Ponderosa pine type.
2 Douglas fir-ponderosa pine transition.

3 D. b. h.=diameter 4.5 feet above the ground, or at breast height.
4 "A rotation is the average normal period of years required to reproduce, grow, and harvest an even-aged crop of trees in a given area of land." Chapman (*3, p. 285*).[5]
5 Italic numbers in parentheses refer to Literature Cited, p. 80.

GRAZING ON FOREST LAND

Practically all forested land in the Southwest, irrespective of ownership, is used for stock grazing. Grazing is on a fee-per-head basis in the national forests, and generally on a lease-per-acre basis on other public land and on private land not grazed by the owners. This means an annual return to the owner averaging between 1 and 2 cents per acre, gross, on national-forest lands, and somewhat higher on Indian reservations and private lands.

TAXATION

Although it cannot be said that the present system of forest taxation has been an appreciable factor in the practice of forestry on private lands in the Southwest, experience in other regions indicates that it might prove to be a serious handicap.

OWNERSHIP

As has been pointed out, the rate of tree growth in the Southwest is very slow and financial returns are low. Large-scale railroad logging, which is the prevailing system under present economic conditions, is facilitated by extensive holdings under a single ownership. The most far-reaching economic values of forests, including watershed protection, benefit the public on a broad community basis, rather than the individual. All this points to public ownership as the most logical and practical foundation for forestry in this region. From this point of view it is, therefore, very fortunate that 88 percent of the total forest land is already in public ownership, about three-fourths of it included within national forests. The several States are practicing varying degrees of forestry on their smaller holdings. Arizona, through a cooperative arrangement with the Forest Service, has obtained the same forest practice on some 20,000 acres of land as is applied on adjacent national-forest areas. A similar agreement has been made effective with New Mexico.

Economic conditions, it is believed, will lead to the acquisition by the public, probably the Federal Government, of most of the area now in private ownership. Already various land-exchange acts permit acquisition by the United States Government of privately owned timberland within the national forests in exchange for government-owned stumpage or land, and a considerable acreage has been added to the national forests in Arizona and New Mexico in this way. Large areas still remaining in private hands within the two States unfortunately have been logged under destructive methods. Because of the great economic loss in unproductive lands and the great cost of reclaiming them, it is obviously advantageous that public agencies either acquire the timber before these lands are logged or make suitable provision to insure conservative logging, fire protection, and other measures necessary to maintain the land in productive condition.

PUBLIC SENTIMENT

Although the general public is coming to understand the importance of timber production, the indirect benefits from the forest appeal most to the average citizen.

An enlightened agricultural population appreciates the value of a forest cover in its protective influence on the watersheds from which domestic and irrigation water is obtained. Extensive irrigation development is dependent in great measure upon large streams such as the Gila River, Rio Grande, and Salt River. Public sentiment in irrigated sections should be an effective force in demanding conservative handling of the forest lands which affect their water sources, irrespective of ownership.

As is the case all over the country, the construction of roads and trails into previously inaccessible mountain areas in the Southwest is giving a great impetus to forest recreation. Similarly, interest in fish and game is increasing. All this develops a sentiment which, while not particularly interested in keeping forest lands productive per se, does deplore forest destruction and in many instances would go so far as to prohibit any cutting whatsoever. In any event, it favors the retention of forest lands in public ownership, subject only, at the most, to restricted cutting.

HABITS AND REQUIREMENTS OF FOREST TREES

Adequate appreciation of the forestry measures prescribed later in this bulletin can be had only through an understanding of the climatic and other conditions encountered, and of the habits and requirements of different tree species. Other publications (*1*, *11*, *12*) treat these subjects more fully, and therefore only the most salient features will be discussed here. The greater portion of the region is characterized by low annual precipitation and sharp seasonal and annual variations in its distribution. In the lower altitudes of the Southwest, protracted droughts accompanied by high winds in early summer and in autumn are trying on vegetation. Fire hazards are also high during these seasons.

Drought alone is usually thought to account for the slow growth and restricted occurrence of trees in the Southwest. Low temperature, however, is also a limiting factor. Trees whose heat requirements are relatively high, such as ponderosa pine, are found in middle altitudes which, as compared with higher levels, have a warm, dry climate. Ponderosa pine would produce much heavier stands at altitudes above 9,000 feet, where the precipitation is around 30 inches, but for the fact that the temperature is too low. Ponderosa pine is here replaced by Douglas fir and white fir, both of which have lower heat requirements and higher moisture requirements.

Since temperature and precipitation are influenced in opposite directions by elevation (fig. 2), especially favorable conditions with respect to the two factors seldom coincide. As one factor approaches the optimum for a given species, the other becomes limiting. This relation governs the distribution of species and causes the forests to be divided into well-defined altitudinal belts or zones, known in forestry as forest types. In the Southwest the main forest types, in order of altitude, are pinon-juniper or woodland, ponderosa pine, Douglas fir, and Engelmann spruce. The woodlands, though of considerable local importance for fuel and fence posts, yield no saw timber and are not regarded as coming within the scope of this bulletin. Of the three saw-timber types, ponderosa pine occupies the lowest, warmest, and driest zone, Engelmann spruce the highest, coldest, and wettest, and Douglas fir is intermediate.

Figure 3 shows the monthly temperature and precipitation by forest types in northern New Mexico. Corresponding graphs for

Arizona and the southern Rockies are very similar, except that in Arizona the winter precipitation is higher and the May-June precipitation lower. In the Black Hills the May-June precipitation is higher and the July-August precipitation lower than in the Southwest.

PONDEROSA PINE TYPE

GENERAL FEATURES

Because the ponderosa pine type contains 85 percent of the saw timber and is the most accessible, it is by far the most important type

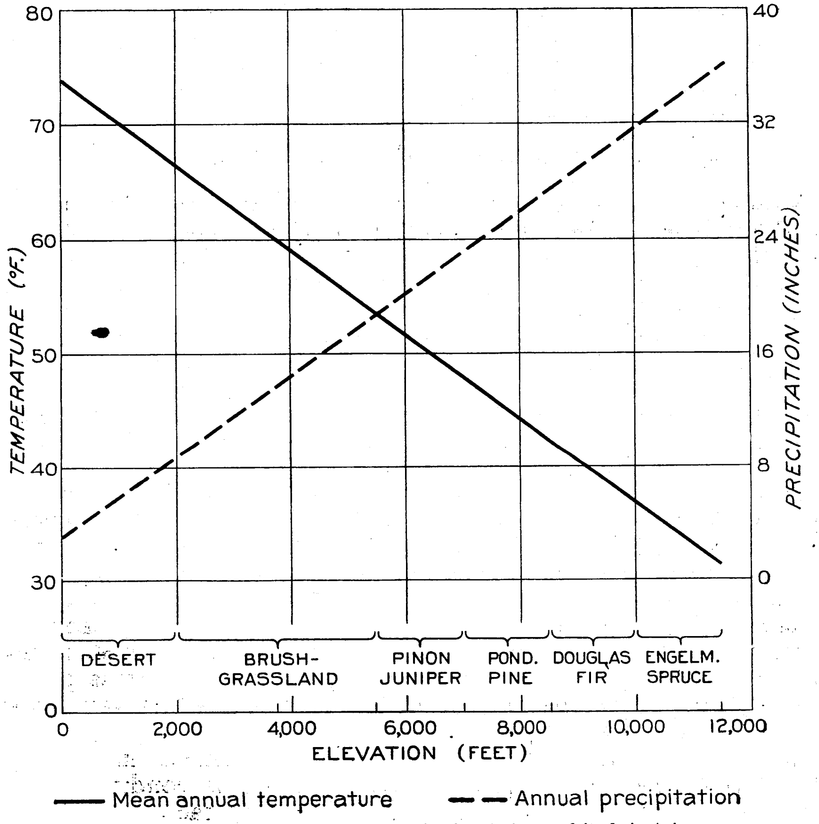

FIGURE 2.—Temperature and precipitation in relation to altitude in Arizona.

in the region from the standpoint of timber production. The optimum altitudinal range in the Southwest is from 7,000 to 7,800 feet. At the lower limit it grades into woodland, and at the upper limit and in other moist, cool situations, there is an admixture of Douglas fir, white fir (*Abies concolor* Lindl. and Gord.), and blue spruce (*Picea pungens* Engelm.). In the Black Hills the pine is usually in pure stands but over limited areas occurs with a light mixture of white spruce (*P. glauca albertiana* (S. Br.) Rehd.). Because of the northerly latitude of the Black Hills, the altitudinal occurrence is relatively lower, but the range is greater, extending from 3,500 to 7,200 feet.

This type is characteristically a pure stand of ponderosa pine and occurs as extensive uniform bodies, unbroken except for occasional

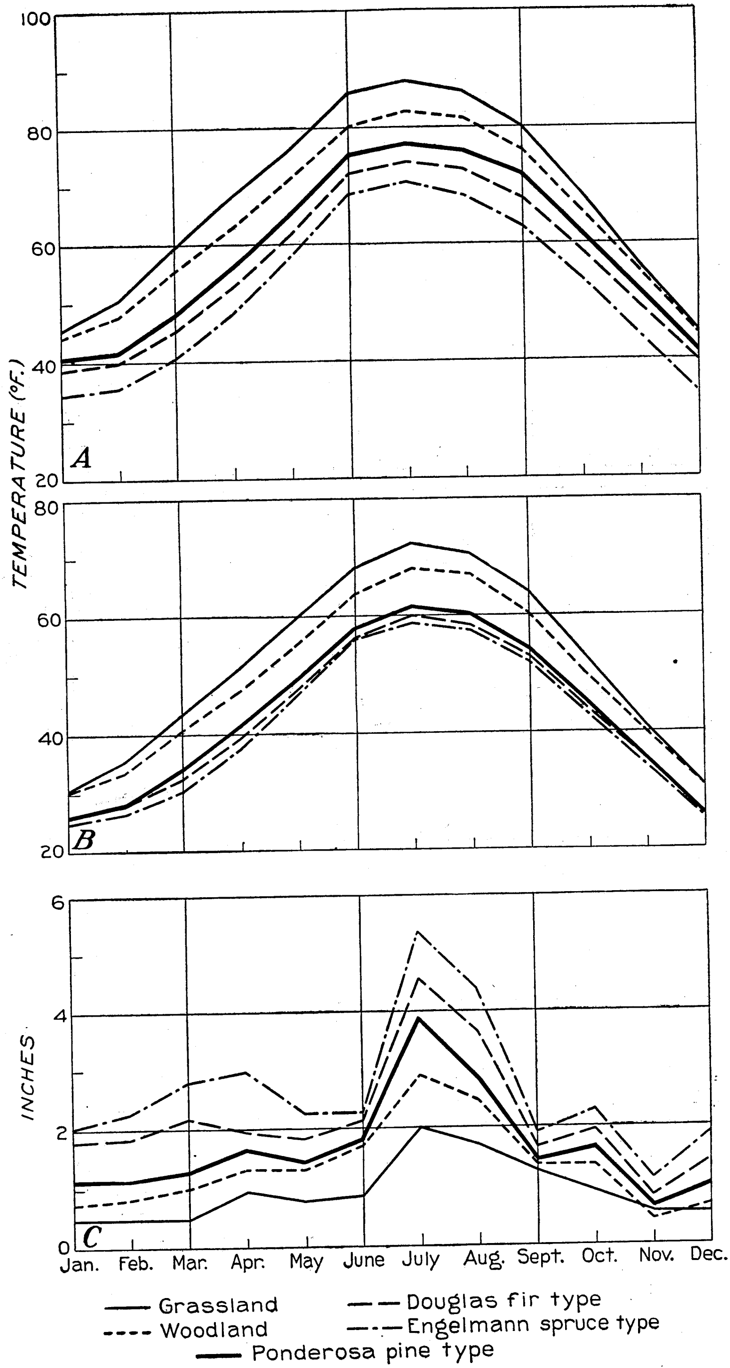

FIGURE 3.—Temperature and precipitation in five vegetational zones of north-central New Mexico: *A*, mean maximum temperature; *B*, mean temperature; *C*, precipitation.

openings known as parks or prairies. The best large body of ponderosa pine timber is on the Sitgreaves National Forest, where the total stand of 4 billion board feet averages 10,000 feet per acre. On the Coconino National Forest it averages about 7,000 feet per acre; in northern New Mexico, Colorado, and the Black Hills, from 4,000 to 6,000 feet.

Ponderosa pine differs widely in density and other features in various parts of the region. In the Black Hills are dense stands of slender trees which reach maturity in about 140 years. In northern Arizona (fig. 4) the stands are typically open, many-aged and strongly grouped, but individual trees grow to larger size than in the Black Hills. From 150 to 200 years, depending upon the site and the size desired, are required to produce saw timber. The southern Rockies

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FIGURE 4.—Mature stand of ponderosa pine on the Colorado Plateau. Small areas yield as high as 40,000 board feet per acre, and blocks of manv square miles will average 15,000 to 20,000 feet per acre.

present conditions intermediate between the above extremes of density, distribution, size, and age (fig. 5).

Changes in the physical appearance of ponderosa pine correspond with three broad age classes that are so universally recognized in cutting practice and silvicultural work generally as to deserve formal definition. Trees of 200 years and older are characterized by a deep yellowish or cinnamon-brown bark and a more or less flat top, and are known as "yellow pines". Those of 150 years and less have a dark, nearly black bark and a round or pointed top; these are "black-jacks". Between these two classes are the "intermediates", having a bark less definitely brown than the yellow pines—often brown on one side of the bole and black on the other—and with a rounded top tending to flatten out.

IMPORTANCE OF NATURAL REPRODUCTION

Natural reproduction is essential both as a means of restocking cut-over or burned lands and as a means of replacing the trees which die in virgin forests. Artificial reforestation is generally so expensive as to be prohibitive, whereas natural reproduction costs nothing except for protection and, on cut-over areas, a nominal investment in seed trees.

Ponderosa pine seedlings do not thrive under a dense crown canopy, but mature uncut pine stands are usually open enough so that seedlings can grow among the old trees. Such seedlings are termed "advance reproduction" since, when the area is logged, they represent the nucleus of a new timber stand already established. In pine forests which have received adequate protection against fire and overgrazing, advance reproduction is the rule rather than the exception. It is seldom that trees of merchantable size occupy more than half of the ground area; this is because the forests are usually made up of trees of different ages and the older ones are continually dropping out as a result of

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FIGURE 5.—Type of ponderosa pine stand common in New Mexico and Colorado. The trees are of rather small size and are more uniformly distributed than on the Colorado Plateau. Seedlings grow almost under the old trees.

windthrow, lightning, fire, bark beetles, and other causes. By this process of attrition, "holes" are formed in the crown canopy, ranging all the way from a small plot where a single tree has died up to a half acre or more. If complete protection has been provided, the openings thus formed should be occupied by young trees ranging all the way from the seedling stage up to merchantable size. Since, however, few areas have escaped fires over long continuous periods, advance reproduction, if present, is likely to be confined to one or a few age classes. Even where advance reproduction is complete, however, logging will usually leave the land incompletely stocked because some of the young growth will be damaged. Occasionally there may be patches of timber too dense for seedlings to persist beneath; this condition is especially prevalent on the Colorado Plateau where the trees occur mainly in dense, even-aged groups. When cut clean, these leave unstocked spaces from 100 to 300 or more feet in diameter.

Reproduction requires attention throughout the region, and under conditions where external factors interfere too much with natural processes, obtaining it may become a serious problem.

Investigations covering a long period have determined the vital factors and remedial measures concerned in the reproduction of ponderosa pine in northern Arizona (*10*). These findings apply in a broad way to the Southwest wherever conditions are such as to present a reproduction problem. The principal factors are climate, soil, ground cover, seed supply, cutting, slash disposal, rodents, grazing, and fire.

INFLUENCE OF CLIMATE AND SOIL

From the standpoint of forest reproduction, the outstanding climatic feature in the Southwest is the drought period extending through May and June and often to the middle of July. Before this period, in the spring, the soil is moist enough for germination but the temperature is too low. By the middle of May, when the temperature would permit germination, the topsoil has become dry and the seeds lie dormant until the arrival of the July rains. If the rains are copious, germination is prompt and vigorous, but if they are deficient, or of short duration, few seeds germinate and the seedlings that do appear almost invariably die at once. Even with August rains, a secondary drought in September and October sometimes kills large numbers of newly germinated seedlings, and ground-heaving during late fall and early spring adds to the mortality. But the protracted drought of early summer accounts for by far the greatest losses. In Colorado and northern New Mexico the early-summer drought is less pronounced, but here winter killing becomes an important factor. On the whole, the reproduction problem assumes most serious proportions in the sections having a distinctly dry early summer.

Other conditions tend to aggravate the effects of deficient precipitation. Foremost among these are a clay soil, the presence of deep surface layers of volcanic cinders, and luxuriant ground vegetation.

Clay soils are unfavorable to reproduction of ponderosa pine because of their compact structure, which impedes root development and is relatively impermeable to moisture and air. These characteristics are accentuated by trampling of livestock and by logging operations in wet weather. On soils classed as clay loams reproduction is difficult to establish, but when good stocking has been attained heavy stands of timber have resulted. Even planting does not always succeed. A mixture of organic matter, gravel, and stones renders clays more hospitable to young trees. A light cover of leaf litter or herbaceous growth is also beneficial in alleviating the packing and baking tendency of bare clay soils.

Cinder soils represent the opposite extreme in structure and texture. They drain too rapidly and become so dry on the surface that germination cannot take place unless showers occur almost daily. A covering of litter, pieces of wood, or living vegetation is helpful, but rather inadequate. Where cinders are underlain by clay or loam, trees usually make excellent growth once the roots reach these heavier layers. Sandy or gravelly loams represent intermediate conditions between clay and cinders, and they are the best soils for both reproduction and subsequent timber growth.

Ground vegetation acts in two opposite directions. It tends to temper high extremes of heat and drought on the soil surface; it retards run-off, promotes penetration of water, and lessens frost heaving, which is responsible for wholesale seedling losses on bare soils of heavy texture. But after the first few weeks the seedling is no longer dependent upon surface moisture and is less subject to injury by high surface temperature. As the roots penetrate the upper few inches of soil, they come in direct competition with the roots of the grasses, weeds, and bushes which sheltered the seedlings in their infancy. The young pine needles now reach out for sunlight which they need in order to perform their function of manufacturing food for the plant. If the ground vegetation is tall and dense, it becomes distinctly harmful by robbing the seedling of soil moisture and sunlight (*15*). The forester should aim to obtain the early benefits of ground vegetation without too much of its harmful influence in the later life of the seedling. This object can be accomplished in some measure by carefully regulated grazing.

Standing trees act in much the same way as ground vegetation, but their influence is greater. Tree shade favors germination and early survival of seedlings by checking excessive evaporation and high temperature at the surface of the soil. This effect is enhanced by the presence of litter. On the Colorado Plateau very young seedlings are more numerous in the shade zone than in the open, but mortality is high in dense slash, and after 2 or 3 years the surviving seedlings are noticeably undersized. That this effect is not due mainly to root competition from the older trees, as is often asserted, is indicated by the fact that soil moisture remains higher throughout the driest part of the summer in the zone of densest shade and litter than in the open. Herbaceous vegetation, particularly of the grasses which flourish in the sun, has the same undernourished appearance in the shade as do the pine seedlings. The trouble is usually considered as due to deficient light, but heat is as important as light for photosynthesis, or more so (*13*). In either case it is evident that ponderosa pine seedlings require a large amount of direct sunlight for normal development. If the old trees occur sparsely or in fairly open stands, seedlings grow almost under the crowns; but if the old trees are in groups, particularly in a cold climate, large spaces underneath and to the north of the groups remain practically bare of seedlings.

INFLUENCE OF SEED SUPPLY

An adequate supply of seed is obviously of prime importance. In the Southwest ponderosa pine seeds seldom lie over from one year to the next. Good seed crops occur only at intervals of from 2 to 5 years. Reproduction is dependent upon the coincidence of seed crops and abundant, well-distributed precipitation over at least 1, and preferably 2 years. Since both seed crops and rainfall are more or less erratic, the element of chance governs to a large extent. Although this uncertainty cannot be eliminated, it can be lessened by providing enough seed trees so that when natural conditions are favorable the supply of seed will be sufficient.

Estimates based upon results of broadcast sowing, together with calculations of the volume of seed production in years of good reproduction, have placed the minimum seed supply for the Southwest at approximately 8 pounds per acre. Assuming an average yield of 2 pounds per tree, this would call for four seed trees. In practice, the yield of the average seed tree is less than 2 pounds and much of this is sure to be consumed by rodents. Therefore, when specifying that four seed trees per acre are required, it is assumed that a considerable additional quantity will be contributed by young trees too small to be rated as effective seed bearers.

Fairly large trees are usually required to produce seed in adequate quantities. Although trees down to 10 or 12 inches in diameter are often described as "loaded" with cones, actual measurement of the yields has shown that the quantity is small as compared with that of large trees. Moreover, only a small proportion of the trees in the lower diameter classes are cone bearers. A comparison of yields of 100 trees felled in 1913 (*10*) gave the average number of pounds of seed per tree for different diameter classes as follows: 12- to 18-inch trees, 0.44 pounds; 18- to 24-inch trees, 1.19 pounds; 25- to 30-inch trees 1.37 pounds; trees over 30 inches, 1.28 pounds. Germination tests have given somewhat higher values for immature than for mature trees, but the difference is not consistently great enough to warrant recognition. The minimum diameter limit for effective seed production in the Southwest, which varies somewhat with the character of the stand and the locality, has been placed rather arbitrarily at 21 inches, although in New Mexico and southern Colorado where the trees are more numerous and a smaller quantity of seed appears to be needed for reproduction, the limit might be lowered to about 19 inches. Theoretically, it is possible to leave enough small trees to produce the required volume of seed, but this does not always work out well in practice because, while such trees may be sufficient in number, they may occur in large groups. Under these circumstances, a large proportion of the seed falls directly under or near the tree groups where seedlings cannot grow. and relatively little reaches the clean-cut areas to be restocked.

Of no less importance than the size of the tree selected as a seed bearer is its physical condition. Mechanical injuries to the bole apparently do not lower the seed yield, but rather pathological agencies, such as mistletoe and leaf diseases. There also appear to be inherent differences in fruiting capacity which cannot be explained by the character of the crown or foliage, but are indicated by the quantity of old cones on the ground, representing the production in several seed years. It is obviously important to select trees which may be expected to live and bear seed through the reproduction period, and which will grow. Trees over 25 inches or so in diameter are more subject to windfall and lightning than smaller ones and they involve a greater risk of wood capital in proportion to seed yield.

Considering all aspects, the ideal seed tree in the Southwest may be described as a sound, thrifty, large-crowned, well-formed tree, usually between 20 and 25 inches in diameter at breast height, and showing evidence of having borne good seed crops in the past (fig. 6).

In the Black Hills, seed trees as such are rarely needed; where they are needed, trees about 14 inches d. b. h. will usually suffice.

EFFECTS OF CUTTING

Cutting, with its direct and indirect consequences, is the most potent silvicultural agency within the direct control of man. Its direct effect in the removal of seed trees has already been discussed. However, where advance reproduction is present and ample, only 1 or

2 seed trees per acre are needed, their function being to seed up blank spaces caused by logging operations and also the usual stump patches resulting from the cutting of large groups of trees.

As may be gathered from the discussion of advance reproduction (p. 14), the presence and condition of such reproduction should be a prime consideration in cutting. The removal of trees from a stand exercises a strong influence upon moisture, light, and temperature, as has already been seen. When a tree is felled, the soil moisture formerly taken by its roots immediately becomes available to other plants. Neighboring trees usually respond by increased growth. Pine seedlings thrive in these vacated spots if they can become established ahead of other vegetation. The desirability of cutting at a time when young seedlings are on the ground under the trees and before they become suppressed is obvious.

Where advance reproduction is absent, unless pine seedlings become established soon after cutting, weeds and grass may take possession to the exclusion of the pine. Where there has been a prompt response, young ponderosa pine seedlings that pass the first season are benefited by the sunlight admitted by removal of overhead cover. This opening up of the stand may, however, be to the detriment of such species as the firs and spruces. A knowledge of the response of different species to insolation and evaporation makes it possible to employ cutting as a means of controlling the composition of the stand.

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FIGURE 6.—A good seed tree in the foreground. The full crown carries a large leaf area and the pointed top indicates good height growth. The smaller trees in the group to the left bear only small quantities of seed. The large tree in the right background is declining and should not be left for seed.

From the foregoing it is clear that cutting properly timed with reference to seed crops and seedlings already on the ground, and properly regulated with reference to selection of trees to be removed or left, not only permits but distinctly favors natural reproduction. In a fully stocked stand of ponderosa pine, reproduction of this species is impossible without cutting. It is only as surplus soil moisture and adequate insolation become available that seedlings can grow. In nature, these conditions are brought about by the death of old trees; under management, the same effect can be brought about by cutting.

EFFECTS OF SLASH DISPOSAL

One of the inevitable consequences of cutting is a mass of debris or "slash" consisting of tops and branches which have not sufficient value to warrant their removal from the woods. The most obvious objection to slash is that it is a fire menace. Slash fires usually kill all young growth and many old trees. For this reason it is desirable, if the fire hazard is great, especially where advance reproduction exists, to burn the slash under control when weather and other conditions are such that little damage will result.

There are, however, many other angles to the slash question—so many that generalizations must be used with great caution. Whether the presence of slash is intrinsically detrimental or beneficial to forest reproduction depends on many circumstances. Among the factors

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FIGURE 7.—Pulling slash—the tops have been pulled away from seed trees, but in most instances they are still too close for fire protection.

to be considered, aside from fire hazard, are the density and age of the slash, herbaceous vegetation, soil, topography, and grazing. Methods of disposal that do not involve burning the slash are shown in figures 7 and 8.

Slash may also have important silvicultural effects through its influence upon soil conditions. A layer of slash so deep and dense as to cover small seedlings and prevent seeds from reaching the soil is obviously undesirable. After such masses have broken down, however—a matter of 10 to 15 years or even more—seedlings may gain a foothold and once established make rapid growth because of the good moisture conditions created by the soil mulch and the absence of competing plants. Eventually the rotted slash adds some organic matter to the upper layers of the soil, but this is a slow process, and the contribution of nitrogen is much less than is generally supposed.

If the ground is occupied by dense, rank-growing grass, such as Arizona fescue (*Festuca arizonica*), a moderate application of slash stimulates the grass at the expense of the young tree seedlings, with the result that the seedlings are likely to be killed by excessive root competition and shade. This effect was clearly evident in the big seedling crop of 1919. If the slash is dense enough to kill the grass, the effect is ultimately beneficial.

On bare soils which are either very fine and compact or very coarse, a moderate cover of slash has proven decidedly beneficial in aiding the establishment of seedlings. The benefits here are clearly in aiding percolation of water and in moderating the high surface temperatures and extreme desiccation which result when such soils are exposed to the direct rays of the sun. Seedlings which gain a foothold in brush-mulched soils devoid of other plants usually make extremely rapid growth. A slash cover helps to check run-off from heavy rains, which

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FIGURE 8.—Lopping and scattering slash. In the present state the soil cover is too dense for good germination, but after the branches break down seedlings can start. The soil is well protected against erosion if grazing is not too heavy in the open spaces.

would carry away the rich surface layers and form gullies; but as a rule, slash alone should not be relied upon to stop erosion, since it is seldom adequate in quantity to cover all the ground surface. Rather, it should be scattered in denuded spots to supplement natural cover.

Another important benefit of slash is that the seedlings which come up in it are protected during infancy against grazing damage. It is quite common on overgrazed cut-over areas to find that almost the only remaining seedlings are in old top slash (fig. 9). The explanation formerly given for this was that slash created favorable conditions for germination. Investigations on the Colorado Plateau in 1920 and 1921, however, showed that usually more seedlings actually started in the open than in slash, but that most of those in the open were killed wherever grazing was heavy, whereas those in situations protected by slash remained unharmed (*10*). Although these seedlings became exposed to browsing as they grew up through the branches, they had by that time passed the stage in which browsing is directly fatal.

The favorable and unfavorable effects of slash may be summarized as follows: It favors absorption of water, decreases evaporation, tempers extremes of heat, adds organic matter to the soil, retards run-off, and protects young seedlings from browsing by livestock. On the other hand, it increases the fire danger, it favors the increase of injurious rodents, it may cover seedlings or hinder germination, and it may encourage the growth of coarse grasses at the expense of tree seedlings. Whether the benefits will outweigh the unfavorable effects or be outweighed by them on a given area can be predicted only by carefully considering all the factors involved and their relative mportance on that particular area.

FIGURE 9.—Pine seedlings which have survived overgrazing because they were protected by logging slash in their infancy. Grazing damage has been light in more recent years.

EFFECTS OF GRAZING

On extensive areas, particularly in northern Arizona, ponderosa pine reproduction is known to have been arrested for many years by adverse grazing influences. Since 1926 the situation has been greatly improved, mainly as a result of lighter stocking, improved distribution, and a shortening of the grazing season. The most significant facts developed in dealing with this problem are briefly as follows:

(1) Overstocking is the primary but not the sole cause of damage to forest reproduction.

(2) Ponderosa pine seedlings less than 3 years old are the most susceptible to fatal grazing injury.

(3) Both cattle and sheep may do severe damage, though usually under somewhat different conditions.

(4) Under conservative grazing, most of the damage occurs in early summer and in the fall, being relatively light in midsummer.

(5) Grazing can be directed in such manner as not only to decrease damage to a negligible figure, but also to aid the establishment of pine seedlings.

It is axiomatic that if a tendency exists for livestock to eat pine seedlings, two animals will do more damage than one. If there is a shortage of forage, the amount of damage may increase out of all proportion to the number of animals. On many livestock allotments of the Coconino, Kaibab, and Sitgreaves National Forests, the stocking after 1926 was only from 50 to 75 percent of that which prevailed before 1926. By 1929 the effect of these reductions on seedlings had become very marked. On an extensive series of plots current damage to 80 to 100 percent of the seedlings before 1926 was reduced to a negligible percent by 1929. Shortening the grazing season and obtaining better distribution played their part, but these are, in effect, merely forms of reduced stocking. That damage generally has persisted on areas of concentration while virtually disappearing from most areas of lighter use points to overstocking as a major factor. Certain areas on which conservative stocking and good management as regards forage have not done away with excessive damage to tree seedlings—although they are the exception rather than the rule—indicate that under certain conditions good range management may have to be supplemented by additional safeguards if damage to forest reproduction is to be kept under adequate control.

Investigations following the abundant pine germination of 1919 on the Colorado Plateau have shown that the first 2 or 3 years in the life of the young pine seedlings are the most critical (*14*). Unless grazing is very heavy, few seedlings are touched during the first year, evidently because most of them are at that time too small to attract livestock. In the second and subsequent years, however, great numbers may be eaten. In 1920, it was not uncommon to see large patches on which nearly every seedling of the 1919 crop had been bitten off or defoliated so severely as to preclude recovery. Contrary to the usual impression, most of the direct damage is done by biting rather than trampling. The reason for the large proportion of fatalities in the second year after germination is that in this stage the seedlings are usually small and relatively succulent; the entire crown may be bitten off or all the leaves may be removed, leaving a bare stem which almost invariably dies. After the plants become older and more woody, they are eaten down less severely and a few of the lower leaves are likely to escape. In this condition they have a chance to recover. Records on several thousand seedlings under many conditions between 1919 and 1929 showed that although during the first year after germination usually less than 10 percent were bitten, nearly all of these were killed outright. In the second season, on heavily grazed areas, from 40 to 60 percent of the remainder were killed outright and from 20 to 30 percent of the survivors were injured. After the second year the percentage killed fell off sharply, but the percentage injured rose and accumulated until by 1924 only about 30 percent of those living had escaped serious injury (fig. 10), and these were mostly in situations where protection was afforded by rocks or logs. Under the much lighter grazing that has prevailed since 1926, relatively few small seedlings have been killed by browsing.

The fate of injured seedlings depends upon many circumstances, such as age and inherent vigor, environment, and finally upon the frequency and severity of subsequent injury. Other things being equal, the older and larger the seedling and the more foliage left after the first injury, the better are its chances for survival. Favorable soil and general growing conditions greatly improve the chances for survival. If the seedling is severely browsed year after year, ultimate death is certain; but if browsing is intermittent or light enough so that a considerable amount of foliage remains, the seedling may persist indefinitely although making little growth. It was formerly thought that pine seedlings which had been thus deformed and impoverished could never recover even if no longer subjected to browsing. In recent years, however, it has been found that they have a remarkable capacity for recovery, once the damage is discontinued. A few years are required to develop an effective leaf

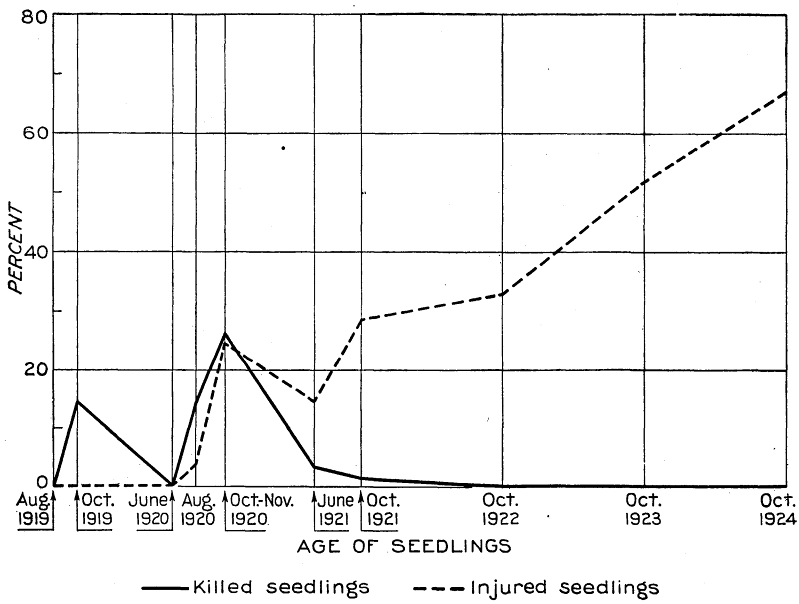

FIGURE 10.—Intensity of grazing damage as related to age of ponderosa pine seedlings germinated in 1919, as shown in percentages of seedlings present at each examination. Injured seedlings are cumulative after June 1921.

area, and then a leader emerges which usually grows at a phenomenal rate (fig. 11).

Until recent years it was thought that cattle were responsible for relatively little damage as compared with sheep. Since prior to 1926 both cattle and sheep generally grazed on the same ranges in localities where damage was prevalent, it was difficult to fix the responsibility as between the two classes of stock. During this period, however, it was widely observed that where reproduction had failed on the open range under dual use, it was almost without exception progressing satisfactorily in adjacent cattle pastures to which sheep did not have access. Many striking examples of this kind are on record. Examples have also been cited in which restocking on the open range was attributed to the absence of sheep during the early life period of the seedlings (*10*). The widespread destruction of small seedlings by browsing under dual use, as recorded on the Coconino, Kaibab, and Sitgreaves in 1920, was negligible in cattle pastures, although older seedlings were sometimes damaged in such pastures. The evidence, though indirect, pointed to sheep as the primary agency in destroying small seedlings. In 1926 cattle were segregated from sheep, and at the same time both classes of stock were greatly reduced in number. Damage, though perceptibly decreased, continued on cattle ranges as well as sheep ranges. But by this time the 1919 seedlings were 7 years old and thus past the critical stage. Seedlings which came up in 1928 and subsequent years suffered but few fatalities from browsing on either cattle or sheep range. This indicates that under conservative grazing small seedlings are in little danger of extermination by either sheep or cattle, even though older seedlings may be subjected to considerable damage. But no evidence has been brought forth to refute the earlier conclusion that heavy sheep grazing was primarily responsible for the wholesale destruction of second-year seedlings in 1920 and earlier periods; nor has any other explanation been offered for the striking contrast between dual use ranges and cattle pastures, which remains in evidence today on the Coconino and Kaibab National Forests.

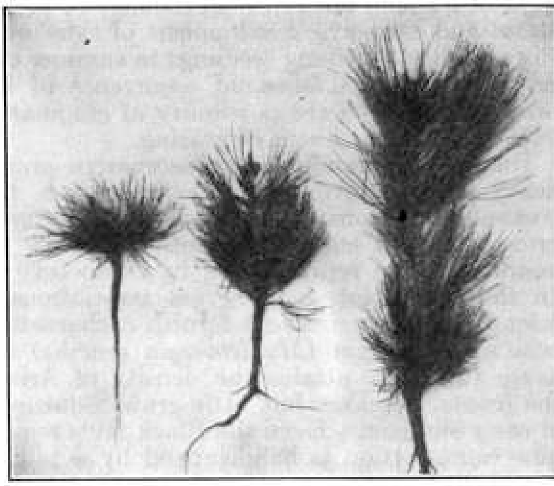

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FIGURE 11.—Pine seedlings in different stages of recovery from grazing damage. All are of 1919 germination and were subjected to severe damage between 1920 and 1926. The one at the left still has no leader but has developed a dense mass of leaves. That the other two have but recently emerged from this condition is evidenced by the dense mass of needles and fine branchlets and the pronounced bend in the main stem near the ground line.

Hill's (*5*) investigations between 1910 and 1917 indicated somewhat more damage at the height of the dry season of June and early July and also in the autumn than during the summer rainy season. In the light of later experience, the absence of clear-cut seasonal differences may be attributed to the fact that at the time of Hill's investigations and up to 1926 overgrazing was generally so extreme and widespread as to mask the effect of other factors. Under the more conservative grazing of recent years, seasonal variations in the extent and degree of damage have become very outstanding. This is true particularly of damage to the terminal shoots or "leaders", which is at its worst in the latter half of June and practically ceases after July 15. Except under extreme overgrazing, pine shoots are not eaten after they become woody, which normally occurs early in July. The time when they are most readily eaten is when they are growing vigorously, usually from about June 10 to July 5, varying with the year and the locality. This period is coincident with the period of the grazing season when green forage is at a minimum, which doubtless is a contributing factor. Young seedlings grow through the summer and thus are an exception to the rule. After the second year, terminal growth usually ceases in July, but vigorous specimens, even in the sapling stage, occasionally make a short second growth after the summer rains get under way. Pine needles are not browsed to any great extent after their first season except under very heavy grazing. Needle browsing on current year's shoots usually begins about August 1 and increases during the fall months. Unless it approaches complete defoliation or is repeated year after year on the same tree, the effects are not serious. Unfortunately, however, there is a tendency for repetition of damage on the same areas. Leader damage not only retards height growth, but also tends to deform the young tree. After seedlings are 5 or 6 years old they have an amazing capacity for replacing lost leaders, but repeated damage of this class results in crooked stems and excessive development of side branches. Aside from the susceptibility of young seedlings to summer damage due to prolonged growth, the usual seasonal occurrence of both leader and needle browsing suggests the possibility of eliminating most of the damage by seasonal curtailment of grazing.

Under most conditions, conservative grazing as contrasted with heavy grazing favors forest reproduction, but there are some important exceptions to this rule. Wherever herbaceous vegetation grows tall and sufficiently dense to shade most of the ground, it handicaps pine reproduction by competing for moisture and light. In the Southwest, bunch-grass associations dominated by Arizona fescue (*Festuca arizonica*) furnish a characteristic example. Mountain muhlenbergia (*Muhlenbergia gracilis*) is less objectionable because it seldom attains the density of Arizona fescue, and, unlike the fescue, it makes but little growth during the critical dry season of early summer. Even the Black Hills region has its sites on which pine reproduction is handicapped by a tall, dense grass cover. In northern Arizona, records of the 1919 seedling crop (*10*) proved beyond question that luxuriant stands of bunch grass interfered with pine reproduction (fig. 12). These records also showed that whereas browsing by livestock was responsible for the death or injury of numerous seedlings, the seedlings in many instances owed their existence to heavy grazing which cropped the bunch grass close to the ground. Even more positive evidence is furnished by an experiment on the Kaibab, started in 1928, in which rodent-protected plots in nearly pure Arizona fescue were seeded to ponderosa pine and periodically clipped to various heights or entirely denuded of grass (*15*). In both number and size of seedlings surviving at the present time, the plot clipped to 6 inches is far superior to the untreated plots, the 2-inch clipping excels the 6-inch clipping, and the denuded plot outranks all others so far that it must be placed in a class by itself. These results are corroborated by natural reproduction originating in 1928 and 1929 on neighboring bunch-grass land. Where Arizona fescue approaches a virgin state, seedlings of the 1928 or 1929 classes are very scarce; but where the grass is of less than 0.1 density, or where it has been replaced by a sparse growth of weeds, seedlings are usually present in gratifying numbers. (Areas of the last class are usually devoid of 1919 seedlings because they were mostly killed

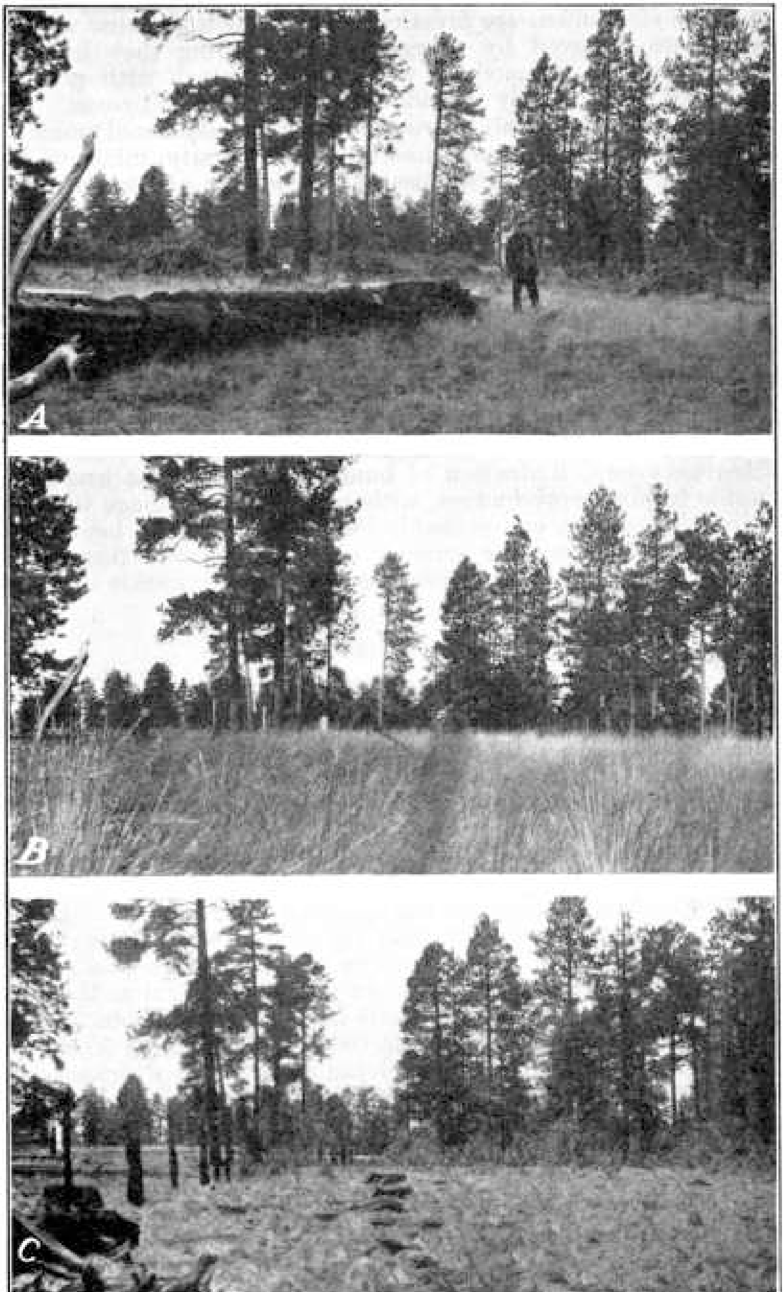

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FIGURE 12.—Opening in ponderosa pine forest after logging: *A*, Immediately after logging (1909); ground occupied by Arizona fescue, no advance reproduction. *B*, Five years later; area fenced, no grazing, grass very luxuriant, no reproduction. *C*, Twenty years after cutting; still no reproduction in the dense grass, matted down by preceding winter's snow, but good reproduction appears where grass was of only moderate density and luxuriance.

by grazing in 1919 and 1920.) Sites comparable to the denuded plot in the 1928 experiment are practically nonexistent, because where the grasses were removed by overgrazing or logging they have been almost invariably replaced by weed growth, which with pine litter and logging slash usually provide somewhat of a soil cover. Absolutely bare soils occur only in roadways or on occasional small spots where removal of the topsoil has rendered the site inhospitable to any form of vegetation. Because of invasion by plants unpalatable to livestock, only the most extreme and prolonged overgrazing results in denuding pine-bunch-grass sites. Ultimate recovery of such sites must await the establishment either of bunch grass or of pine-seedlings in sufficient numbers to form a continuous needle litter. If Arizona fescue takes possession first, the chances for pine reproduction are greatly decreased.

Although overgrazing bunch grasses to the point of denuding the soil is not advocated, grazing that keeps them down to a height of 6 inches will encourage pine reproduction and at the same time lessen the fire danger which is a threat to young pine stands in the bunch-grass type. Reduction of bunch grass to height and density favorable to pine reproduction, without excessive damage to already established seedlings, can probably be accomplished by heavy stocking with cattle during the summer rainy season and through September, accompanied by exclusion or adequate restriction during the early-summer dry season.

DOUGLAS FIR TYPE

GENERAL FEATURES

The usual altitudinal range of the Douglas fir type in the Southwest is from 8,000 to 9,500 feet. Douglas fir is the dominant species, commonly occuring in mixture with white fir and limber pine (*Pinus flexilis* James) or Mexican white pine (*P. strobiformis* Engelm.). The type is found on moister, cooler sites than the ponderosa pine type, and on drier and warmer sites than the Engelmann spruce type. There is more or less intermingling with ponderosa pine in the lower and with Engelmann spruce in the upper altitudinal range. Douglas fir forests are generally denser than the pine forests. It is probable that on the best sites this type can be made to produce saw timber in from 120 to 150 years. Maximum yields are found in the Sacramento and Graham Mountains where large areas run from 20,000 to 30,000 board feet per acre, and selected areas as high as 50,000 feet. In northern New Mexico and Colorado, the yield averages much lighter. Mature Douglas fir forests are chacteristically more patchy than those of ponderosa pine, being broken up by burned areas usually grown up to aspen (*Populus tremuloides aurea* (Tid.) Dan.).

IMPORTANCE OF NATURAL REPRODUCTION

The problem of restocking in the Douglas fir type is very often solved by the presence of advance reproduction; all species in this type except ponderosa pine are fairly tolerant of shade. Under such conditions fire protection becomes the primary consideration. As in ponderosa pine stands, the preservation of a growing stock made up of thrifty young trees is of great importance. In a fair proportion of the Douglas fir type, there are sufficient trees below 16 inches in diameter to form a satisfactory growing stock. Unrestricted tie and prop cutting removes too many of the larger trees of this class, and if the operations are repeated devastation will be the ultimate result.

Where advance reproduction does not exist at the time of logging, the problem of restocking demands serious attention. Such is often the case in the heaviest stands in the border subregion. The requirements for reproduction of Douglas fir, the most important species of the type, have not been fully determined. It is known, however, that seed trees are indispensable and that the density of the crown canopy and the character of the seed bed are important factors.

Although seed production has not been studied in the same detail for Douglas fir as for ponderosa pine, it is evident that the general principles are the same. Fairly large trees with full healthy crowns bear the most seed. On account of the great number of medium-sized, immature trees present in most Douglas fir stands, a smaller number of large trees than is required in the ponderosa pine type will usually suffice.

Soil moisture is usually regarded as the all-important physical factor; it probably is dominant, but heat, light, and atmospheric humidity are also important. At the lower limits of the type and on southerly exposures, deficient soil moisture and high evaporation are the critical factors. Near the upper limits of the type and on northerly exposures throughout the upper half of the Douglas fir range, deficient heat is likely to be more limiting than deficient moisture. But even in the high altitudes where the climate is generally cool and moist, sites exposed to high wind or strong sunlight may impose drought conditions by inducing excessive transpiration. Douglas fir is very susceptible to winterkilling; this is true especially in Colorado and northern New Mexico. Unseasonable frost is another factor that may prevent or seriously retard seedling growth on certain sites. Douglas fir is more susceptible than most species to freezes in late spring after growth has begun.

Removal of trees by cutting or other means decreases root competition for the time being and, theoretically, should increase the soil moisture. Undoubtedly, the moisture available to well-rooted seedlings is increased, but opening the crown canopy accelerates evaporation and this decreases the moisture content in the upper inch or two of soil. Drying out of this superficial layer is fatal to germinating seeds and tender seedlings. Exposure to strong insolation also accelerates the rate of transpiration, and thus, though the total available moisture supply may have been augmented, this increase may be offset or overbalanced by increased water consumption. Opening the crown canopy may also stimulate the growth of weeds and brush which, if dense, exact a heavy toll from the moisture supply. It is safe to say that usually cutting increases the moisture supply available to older seedlings; but carried to the extent of exposing large portions of the soil area to wind and direct sun, it tends to create an unfavorable moisture balance for young seedlings.

Light, in the technical sense, is probably seldom a limiting factor in reproduction of Douglas fir, but the heat of direct sunlight may be needed in the cooler situations. Low temperature is the factor which directly limits the upper range of Douglas fir in the Southwest. On sites where the air temperature is below the optimum, the heat made available under direct sunlight may be the deciding factor in favor of survival. Of the associated species, alpine fir and the spruces have lower heat requirements than Douglas fir, ponderosa pine higher, and white fir very nearly the same. This means that on north exposures above the middle range of Douglas fir, the crown canopy should be opened up as much as is consistent with seed supply and wind protection. Unless this is done, alpine fir (*Abies lasiocarpa* (Hook.) Nutt.), blue spruce, and Engelmann spruce are likely to take possession. White fir is also favored in shaded situations, though perhaps less on account of low heat requirements than low light requirements and ability to become rooted in litter. On relatively warm sites, such as south exposures, large openings favor ponderosa pine or limber pine. On such sites, Douglas fir comes in well under light or moderate cover.

Douglas fir requires a mineral soil for permanent establishment of seedlings, but this should not be interpreted as meaning a bare soil. A bare soil dries out too fast on the surface. An inch or two of well-decayed organic matter on the surface, underlain by mineral soil, provides ideal moisture conditions. In the absence of decayed material, leaf litter, stems, etc., if not too deep, are beneficial. The deep layers of more or less dry, undecayed, or only partially decayed duff usually found under tree groups are unfavorable to seedlings unless this material becomes thoroughly soaked and stays wet throughout the first season. Such a condition is brought about only in years of exceptionally heavy summer rainfall.

What has been said about cutting and seed bed has a direct bearing upon brush disposal. In exposed situations where the stand is too open to give adequate protection to the soil, scattering brush may be of appreciable benefit. On the other hand, on cold, shaded slopes, unburned slash is an obstruction to the much-needed sunlight. On such sites undecayed litter is usually deep and thus slash left on the ground aggravates an already undesirable condition.

In Colorado, Roeser (*16*) has found that the best reproduction of both Douglas fir and Engelmann spruce is obtained under the shelter-wood method of cutting, although nearly as good results were obtained by the selection method. In both of these methods crown cover plays an important part by decreasing wind and evaporation. The cutting is not heavy enough to open up the crown canopy excessively, and yet the removal of some of the trees decreases root competition. The method of brush disposal has not been found to influence reproduction of Douglas fir in a marked degree, one way or the other. The findings in Colorado should apply to northern New Mexico where conditions are quite similar. In southern New Mexico and southern Arizona, however, experiments comparable to those in Colorado have given negative results, indicating that here we are dealing with other factors more potent than method of cutting or brush disposal.

Grazing presents less of a problem in the Douglas fir type than in the ponderosa pine type. This is because use of the Douglas fir forests is confined more strictly to summer grazing. Also, the forage during the few months when stock are held in the Douglas fir type is unusually succulent. Douglas fir and white fir seedlings, however, are even more subject to browsing than are ponderosa pine seedlings, and for this reason the danger of grazing damage should not be overlooked.

Fires are generally infrequent in this type of forest, but once started they are very destructive, usually killing everything. Here again the practice of burning slash commends itself. Old burns in which the original stand was almost completely destroyed, occupy thousands of acres. Usually these burns have grown up to aspen which acts as a nurse to such coniferous species as are favored by light shade. On extensive areas where seed trees have been left, aspen-covered burns are being restocked by Douglas fir and other conifers; but where no seed trees occur, reproduction is lacking. Because of the density of the stand after cutting, brush burning requires great care in order to avoid killing young trees.

ENGELMANN SPRUCE TYPE

GENERAL FEATURES

This type occurs immediately above the Douglas fir type and extends to the upper limits of tree growth. It is found mostly above 10,000 feet, though extending lower on northerly exposures. Sometimes the stand is practically pure spruce, but more often this species occurs in mixture with corkbark fir (*Abies arizonica* Merr.) or alpine fir. At the lower limit of the type there is also Douglas fir, white fir, and limber pine. Bristlecone pine (*Pinus aristata* Engelm.) occurs sparingly, being confined to openings on the south and west slopes. Spruce stands are denser than those of the Douglas fir type.

Precipitation is not appreciably higher at these altitudes, but the temperature is lower and therefore evaporation is less. Snow persists well into June. The severe drought of May and June which characterizes the low altitudes in Arizona and New Mexico is scarcely perceptible in the spruce forests.

All of the species except bristlecone pine, which grows mostly on open, exposed sites, are able to make good growth in moderate shade. Maximum yields reach 30,000 board feet per acre for small areas in the Graham and San Francisco Mountains. Yields as high as 50,000 feet are reported for the upper Rio Grande Basin of Colorado. On the average they are not over 10,000 feet per acre for large bodies, and sometimes still less. The spruce, like the Douglas fir type, is very patchy because of old burns probably preceded by insect attacks. Large areas have grown up to aspen, but on many of these the conifers are returning. Other areas, usually in high altitudes, remain bare of both aspen and conifers.

IMPORTANCE OF NATURAL REPRODUCTION

The reproduction problems of the Engelmann spruce type are similar to those of the Douglas fir type. To a large extent they are solved by the presence of advance reproduction. Where advance reproduction does not occur at the time of cutting, real difficulties are encountered. Because of the extremely delicate character of Engelmann spruce seedlings in this region, the need for adjustment of temperature and moisture conditions to their requirements is even greater than in the case of Douglas fir. They are extremely sensitive to drying of the surface layers of the soil during and for several months after germination. This is probably the reason why the type tends to avoid south exposures. Although Engelmann spruce and alpine or corkbark fir are distinctly cold-climate trees, there are indications that reproduction is hampered by low temperature on north slopes at altitudes above 10,500 feet. Seedlings start under cover on such slopes, but they do not grow well, and usually die at an age of 3 or 4 years. Better growth is made in large openings, but germination is poorer. In practice it is extremely difficult to so regulate cutting as to obtain the proper control of surface soil-moisture and temperature. The problem is further complicated by the fact that spruce stands when disturbed by cutting are subject to windfall.

Deep layers of undecomposed litter are detrimental to both spruce and fir reproduction, but especially to the spruce. These accumulations are greatest on the coldest sites. On such sites the burning of slash is desirable if it can be accomplished without too much damage to the residual stand. Although fires are uncommon in the spruce forest, they are extremely destructive when they do occur.

As previously stated, Roeser (*16*) has found the shelter-wood and selection methods of cutting best for reproduction of both Douglas fir and Engelmann spruce.

SUSCEPTIBILITY TO DAMAGE AND DISEASE

INSECTS

Several species of bark beetles are more or less common, and have demonstrated their ability to kill timber in large quantities. The Black Hills beetle (*Dendroctonus ponderosae* Hopk.) has been the most destructive. In a period of several years around 1900 it killed over half a billion board feet of ponderosa pine in the Black Hills. Between 1920 and 1925 the same beetle was responsible for the loss of 300 million board feet of ponderosa pine on the Kaibab National Forest in northern Arizona. This insect is not known to have assumed epidemic proportions on the Colorado Plateau south of the Colorado River.

Dendroctonus barberi Hopk., associated with *D. approximatus* Dz. and *Ips lecontei* Sw., became sufficiently active on the Prescott National Forest in 1928 and 1929 to call for control operations. All of these beetles are more or less common throughout the Southwest. Although they are generally less aggressive than the Black Hills beetle, they nevertheless account for a considerable timber loss over a period of years. The killing of isolated trees reserved for seed production on certain areas may prove especially serious in its effect upon natural reproduction.

The pine beetles of the genus *Ips* attack mainly young trees in the sapling and pole stages. It has been suggested elsewhere that *Ips* accompanying or following prolonged droughts may account for the excessive thinning, or group killing, of young stands of western yellow pine in the lower fringe of the type. A characteristic of these beetles is that they commonly attack young trees in the vicinity of freshly cut slash.

The spruce budworm (*Cacoecia fumiferana* Clem.) and the hemlock looper (*Ellopia* spp.) are serious pests in spruce and fir forests. The spruce budworm occurs over a wide range. It appears to work more or less intermittently, killing some trees and greatly lowering the vitality of others, but seldom destroying a whole stand. The hemlock looper attacks firs, completely defoliating and killing both old and young trees. Fortunately, this insect has been reported in this region only in the Sacramento Mountains.

Two species of tip moth are prevalent in the Southwest.[6] The most common one, *Rhyacionia neomexicana* (Dyar), deposits its eggs on young pine shoots and the larvae bore in and up the shoot, devouring the tender inside tissues and causing the shoot to die above the point of attack. On extensive areas near the lower border of the pine zone nearly every seedling is injured, greatly decreasing height growth and in extreme cases causing death. From the middle altitudinal portion of the zone upward the amount of damage decreases. The damage also decreases as the young trees grow up beyond the sapling stage. A less common form of injury is by the larvae of *Recurvaria condignella* (Busek) which bore a fine tunnel through the pith.

Certain grubs are known to play havoc with seedlings, particularly in plantations, by devouring the roots. Still other insects cut the roots of very young seedlings, causing them to die in the fall of the first season. Much of the infant tree mortality formerly attributed to drought is thought to be the result of insect activity.

Larvae which feed on the immature seeds of ponderosa pine take a tremendous toll from the seed yield of this species. In some localities this is a very important factor in the failure of natural reproduction.

RODENTS

The most common rodents of the forest are seed eaters, and for this reason they are usually regarded as forest enemies. In this class are mice, chipmunks, and mantled ground squirrels. Although these animals aid to some extent in disseminating and planting seeds and may at times eat insects, their activities are thought to be mainly harmful. Field mice, in addition to eating seeds, may do enormous damage by girdling pine seedlings. Pack rats have been known to cut off or girdle seedlings, but they also cut down competing vegetation. To what extent they eat conifer seeds is not known. Pocket gophers gnaw the roots of conifers along with those of other plants. Their depredations in this respect are probably more than offset by their burrowing in the soil, which, though objectionable in cultivated fields and around stock tanks, is beneficial to forest soils. The mantled ground squirrel also burrows in the ground, which may in part at least balance his seed account. The Bureau of Biological Survey has developed successful methods of poisoning all of the above rodents. It is probable that natural forest reproduction could be materially aided by controlling mice, chipmunks, and mantled ground squirrels. In two series of experimental plots uniformly seeded to ponderosa pine in 1929, the plots screened against rodents contained 1,781 seedlings on August 22, as against 618 seedlings on an equal area of unscreened plots. In a series of Douglas fir plots seeded in 1932, screened plots at the close of the first season contained an average of 81 seedlings per plot as against 2 on unscreened plots.

Tree squirrels are also active seed-eaters, but are placed in a different class because of their esthetic and economic value. Both the Abert squirrel and the spruce squirrel are protected by the Arizona and New Mexico game laws, subject to an open season. The Abert squirrel, in addition to consuming great quantities of pine seed, cuts off the young shoots of pine trees. He has the habit of attacking the

[6] Determinations by the U. S. Bureau of Entomology and Plant Quarantine.

same tree year after year, with the result that the crowns of such trees become greatly thinned and the general vigor reduced. The cutting of shoots in winter often destroys great quantities of first-year cones. The consumption of second-year cones begins in August and continues until the seeds are shed. In years of light or moderate cone yield, it is not uncommon to see practically the entire crop on large areas consumed by the Abert squirrel before the seeds mature. The Abert squirrel should not be exterminated, but his numbers should be limited.

Perhaps the most harmful of all rodents in the forest is the porcupine. He begins eating the bark of pine seedlings when they are 6 inches high and continues throughout the life of the tree. Seedlings and saplings are killed by girdling near the ground; poles and immature trees are deformed by girdling of the main stem near the top. On mature ponderosa pine the damage is confined mainly to the branches and tops, but mature spruce trees are barked any place on the main trunk. On areas where seedlings start sparingly, a single porcupine working year after year can prevent restocking on many acres. On spruce and fir burns and on clean-cut pine areas, occasional saplings which would eventually become seed trees are often killed by the porcupine. Although his work is deadliest on thinly stocked areas, he can practically ruin fully stocked stands of poles or saplings. Extensive investigations of the life history of the porcupine by Taylor [7] have disclosed no useful habits in the porcupine, except that he eats mistletoe, and this is a doubtful asset. Eating the stems of mistletoe does not kill it; on the other hand, it is reasonable to suppose that the porcupine aids in the dissemination of mistletoe by carrying the seeds and by wounding the bark of trees.

PREDATORY ANIMALS AND BIG GAME

From time immemorial, man has regarded wolves, coyotes, mountain lions, bobcats, and other animals which prey upon livestock as traditional enemies, to be killed on sight. Although no figures are available to prove the assertion, it is almost certain that this warfare has resulted in a large increase of the rodent population. It is reasonable to conclude that the killing of carnivora which normally live on mice, chipmunks, squirrels, and porcupines, not to say large browsing animals, is detrimental to the forest. Where the control of predatory animals is deemed necessary in the interest of the livestock industry, it should be accompanied by equally intensive control of the enemies of the forest.

BIG GAME

Some years ago the suggestion that deer might become so abundant as to cause damage to forests was received by the public with skepticism if not amusement. Yet, at that time, excessive browsing by deer was coming into evidence in the Grand Canyon Game Preserve. In 1930 the situation had become so acute that forest officers urged the removal of large numbers of deer (fig. 13.) Similar though less critical conditions have developed in the Santa Catalina Mountains and Mount Graham of southern Arizona, and on the Cibola and Gila National Forests of New Mexico. In some of these areas, deer are

[7] The results of these investigations by Walter P. Taylor, of the Bureau of Biological Survey, have not yet been published.

damaging shrubs and young forest trees to such an extent as to endanger the forest and destroy the forage upon which the deer themselves are dependent. Overstocking by deer is far worse than overstocking by cattle and sheep because deer cannot be removed except as small numbers are killed or captured.

DISEASE

Thus far the greater portion of the research work on tree diseases in this region has concerned the decay of wood. The loss of merchantable timber through decay in the woods is enormous. The cull scale of ponderosa pine in logging operations generally runs between 10 and 15 percent of the total cut. This, however, represents but a small portion of the total loss during a rotation because it does not take into account the large number of trees that have died wholly or partly as a result of decay or which have rotted after being killed by other agencies.

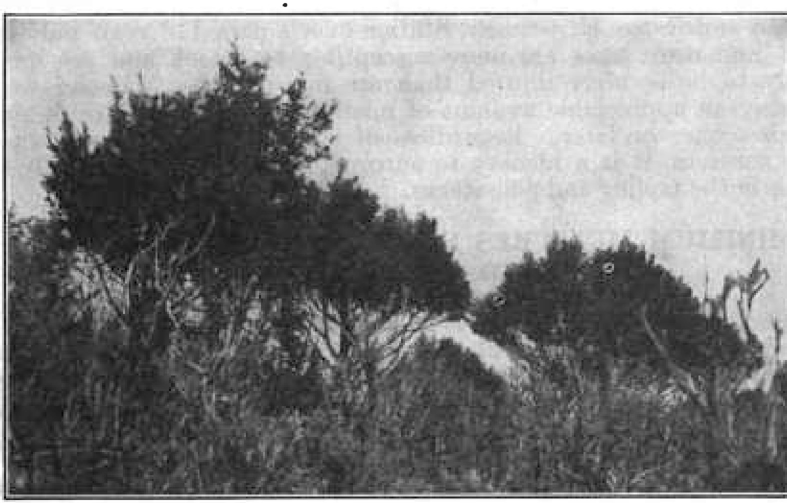

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FIGURE 13.—Juniper defoliated by deer as high as the animals can reach; cliffrose in foreground completely defoliated or killed. Grand Canyon Game Preserve, 1930.

The high percentage of cull due to rot may be attributed in part to the general overmaturity of the forests being logged at the present time. In future generations, few trees will be allowed to attain an age of more than 200 years, and this should automatically decrease the percentage of heart rot. On the other hand, second-growth stands, because of their more limby character, will be more subject to attack by rotting fungi. The heart rots gain entrance mainly through dead limbs which have attained sufficient size to contain heartwood. A practical remedy and perhaps the only one that can be generally applied is to grow young forests in dense stands. If the trees from the sapling stage up through the pole stage are spaced closely enough so that the lower limbs will die before appreciable heartwood has developed, the limbs will not only drop off more quickly and thus permit the formation of clear lumber, but they will not provide a point of entry for heart rots.

A large part of the high mortality in young seedlings is not directly traceable to drought or mechanical injury, and it is reasonable to suppose that pathological agencies play an important part. The common nursery disease, "damping off", is relatively inactive under forest conditions. An ailment known as "blight" is attributed to superheating at the ground line and may be alleviated by providing light soil cover in the form of needle litter, dead branches, and herbaceous vegetation. It seems probable that a thorough study of seedlings would reveal a large number of diseases which are not now recognized.

MISTLETOE

Of the organisms attacking living trees, ponderosa pine mistletoe has received most attention in forest management (*6*). Investigations have shown that mistletoe retards the growth of trees perceptibly and that many trees are killed by it. Records by the Southwestern Forest and Range Experiment Station over a period of years indicate that immature trees are more susceptible to attack and are more likely to be severely injured than are mature trees. Young trees bearing an appreciable amount of mistletoe are almost sure to succumb sooner or later. Regardless of whether a mistletoe-infected tree survives, it is a menace to surrounding trees and especially to those in the sapling and pole stages.

MINIMUM MEASURES NECESSARY TO KEEP FOREST LANDS PRODUCTIVE

Where the growth of trees is as slow as in the Southwest, timber growing as a commercial enterprise cannot as a rule be expected to appeal to private capital. But most forest lands will yield even lower returns under other forms of use.[8] The best outlet for the private owner of cut-over lands should be eventually to sell them to some public agency which, because of important indirect values such as regulation of stream flow or recreation, in addition to timber and forage crops, can afford to own and manage forest lands under conditions that would be unprofitable to the individual. But it is poor economics for the State or Federal Government to purchase cut-over lands for timber growing after they have been abused to such extent that they will not respond to management without large expenditures for reforestation. Lands which bear a fair stand of seedlings and saplings or enough seed trees to insure natural restocking in 30 or 40 years have potential forest value; but lacking both reproduction and seed trees they are a doubtful asset because the cost of planting under most conditions is prohibitive.

Devastated lands are not only unproductive but they may become a public menace. Clear cutting followed by fire and overgrazing may cause floods and erosion and result in untold damage to storage reservoirs, highways, and other property (fig. 14). Also, the land itself deteriorates through removal of the fertile topsoil, so that its productive capacity for both forest and forage crops is greatly impaired. No country can long afford to allow its soil and water

[8] It has been estimated that on the basis of current prices received for stumpage and grazing permits by the Forest Service, the annual per acre growth of ponderosa pine under management and accessible to markets is worth from 5 to 10 times as much as the annual forage growth would be if the same land were clear cut and devoted entirely to grazing. In comparing gross value of products, employment, and other social values, a similar relation exists. The highest returns are obtainable by a judicious combination of timber growing and grazing.

resources to be wasted. Forest destruction is more than a timber problem; it is also a land and water problem which the Nation, the State, and the community must face sooner or later.

As stated in the introduction, the measures prescribed as necessary to keep forest lands productive represent a standard of forest practice that aims but little higher than merely avoiding forest destruction. This brand of forestry, if it may be called such, cannot be expected to produce profitable timber crops except under the most fortunate circumstances. Good stands of timber will grow up on some areas; on others the margin above devastation will be narrow. If these measures succeed in preserving the soil cover and a sufficient number of trees to insure fair natural restocking in the course of 30 or 40 years after cutting, their main object will have been attained. No standards are set as to yields or time of a second cut.

Growing a timber crop involves two major activities—stocking the land and protecting the growing stand. For economic reasons

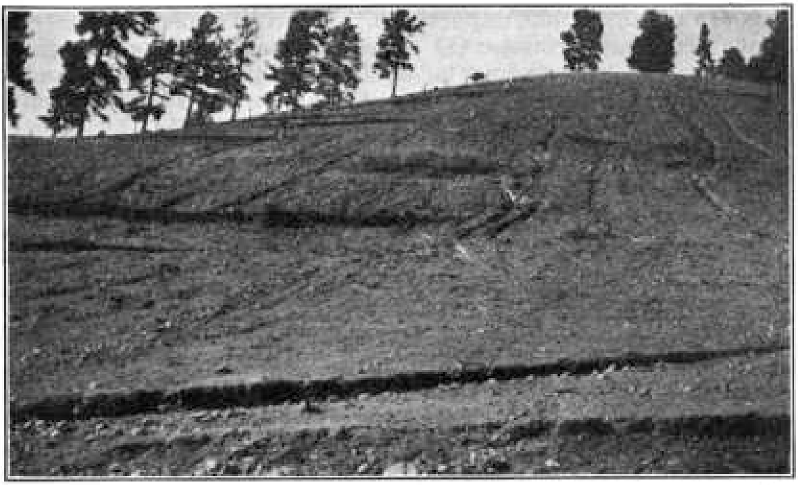

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FIGURE 14.—Soil erosion following heavy cutting, fire, and overgrazing. In addition to the gullies, the topsoil is being removed by sheet erosion.

the land must be stocked mainly by natural means. In regions where adequate reproduction is assured, stocking requires little or no attention unless, as in the Black Hills, young stands tend to become overdense and require thinning. Protection is primarily an aid to reproduction, but it must be continued after stocking is complete. The degree to which a given forest area approaches its full productive capacity depends almost entirely upon the success attained in stocking the land and in protecting the growing crop until it reaches maturity. If the land is only one-half or one-third stocked, or if restocking is unduly delayed, the annual yield will be decreased in corresponding measure. If 10 percent of the land is overrun by fire after cutting, the forest capital on this portion of the area becomes virtually a total loss for 50 years or more. Young pine stands up to 60 years old and fir and spruce of greater age are subject to complete annihilation by fire. Other inimical factors against which protection must be provided are improper grazing, disease, insects, and rodents.

The specific precautions necessary to assure keeping forest lands productive vary somewhat with the species, as well as with climate and industrial practices. Because of its wide-spread occurrence and great economic importance, the ponderosa pine type will occupy the foreground in the presentation which follows, and the measures here prescribed are designed primarily for ponderosa pine. Nevertheless, the other forest types, such as the Douglas fir and the Engelmann spruce, have enough in common with ponderosa pine to permit their being discussed concurrently, and where distinctly different treatment is called for, specific measures will be given. All the measures presented are naturally associated with major forest activities and involve special provision in regard to fire, cutting and removal of timber, disposal of logging debris, and grazing.

FIRE PROTECTION

Measures which will prevent burning of cut-over lands to a substantial degree and which will restrict fires to a minimum in virgin stands are of paramount importance. Protective measures naturally fall into two general classes: (1) Those that have to do with organization—personnel, improvements, equipment, planning, etc.; and (2) methods of slash disposal. In view of the fact that slash disposal has some silvicultural bearing, discussion is simplified by separate presentation.

An effective organization must be able to detect fires quickly, reach them promptly, and extinguish them while they are small. A good example of such an organization is that of the Forest Service in the Southwest. This organization consists first of primary lookouts, stationed on peaks overlooking a large expanse of country, who are continuously on the watch for smokes, and firemen located at convenient points in readiness to proceed to a fire at a moment's notice. The headquarters of all permanent officers are connected by telephone. On sighting a smoke the lookout determines its direction by means of an alidade and protractor, and transmits this information by telephone to some central point, usually the supervisor's office. Corresponding readings are received from other lookout points. Then by intersection or triangulation on a map at the central point the fire is located definitely and the nearest fireman is sent to it. In case of large fires or great fire hazard temporary labor is obtained from nearby ranches, towns, logging camps, etc. All forest users, particularly, are depended on for aid in fire suppression.

It is difficult to outline measures with costs that will fit individual cases accurately, since these vary not only with the region but also with circumstances of individual cases. There is one intangible element without which no mechanical requirements will ever be entirely successful, and that is a desire and determination on the part of operators and lessors of forest properties, and their employees, to prevent and suppress fires.

With this explanation the following is offered as the best statement that can be made as to measures necessary under average conditions, localized, where it seems worth while, by regions:

(1) Protective machinery consisting of a permanent organization supplemented by lookouts and firemen, telephone communication, roads and trails, fire-fighting equipment, and cooperation with Government and private agencies, that will represent a manpower

in every part of the region, except the southern Rocky Mountains, equal to 1 man to every 40,000 acres of virgin timber or 20,000 acres of cut-over land—this to be maintained during a season running from May 1 to July 10 on the Colorado Plateau, April 15 to July 15 in the border region, and May 1 to October 31 in the Black Hills. In the southern Rockies 1 man to 90,000 acres virgin or 50,000 acres cut-over is sufficient, for a season from May 15 to July 15.[9]

(2) The use of oil for fuel, wherever practical to secure it, in all steam-logging machinery.

(3) Efficient spark arresters on all locomotives and other steam-logging machinery and sawmill engines where so located that sparks therefrom might start forest fires.

(4) The equipment of logging locomotives, steam loaders and skidders, logging camps, and sawmills in the vicinity of forest lands with suitable fire-suppression tools.

(5) For each logging operation a written plan of action for the prevention and suppression of forest fires, which will outline the organization of camp or woods personnel, individual responsibilities, etc.

(6) During periods of abnormally high fire hazard, prohibition of smoking on cutting areas; in cases of extreme hazard due to climatic conditions, suspension of operation where this can be shown to be advantageous.

(7) On the Colorado Plateau the prompt felling of dead snags on all cutting areas except spruce; in other regions snags need be felled only on fire lines and areas of special hazard.

(8) Removal of slash and debris on areas of special hazard, usually by piling and burning, in advance of the regular fire season or other periods of fire danger. These areas of special hazard include logging railroad rights-of-way, the vicinity of steam-logging machinery, sawmills, camps, highways, etc.

Paragraph (1) is intended to approximate the intensity and method of organization maintained by the Forest Service. The presence on national forests of year-round administrative officers who augment the purely protective organization renders it difficult to give figures of cost, area per man, etc., comparable with what would be needed by the large private owner organized for protection alone. It should be appreciated also that this organization scheme contemplates large holdings of forest land, and in a region of many small holdings would be adequate only with the utmost degree of cooperation between individual owners.

The average cost of fire prevention, including improvements, on the national forests of Arizona, New Mexico, and Colorado, as shown by the records of the Forest Service, is 1 cent per acre per year, of which half is for improvements.

An organization such as is outlined in the preceding pages will extinguish the majority of forest fires while small and will avoid the expense of additional labor. In spite of all precautions, however, occasional large, expensive fires do occur. For the national forests of Arizona and New Mexico the average annual per-acre cost of suppression, made up largely of the costs of these large fires, is about 3 mills, when prorated against the total forest area. In Colorado

[9] The seasons here given apply particularly to the ponderosa pine type. They usually begin about 2 weeks later in the Douglas fir type and a month later in the Engelmann spruce type.

this figure is placed at 5 mills. The combined cost of prevention and suppression in the Southwest therefore varies from 1.3 to 1.5 cents per acre annually.

In the Black Hills the combined cost of prevention and suppression, including improvements, averages 2.3 cents per acre annually.

The manner in which cut-over areas are intermingled with virgin areas and are covered by common lookouts complicates the differentiation of cost of fire prevention between the two classes of land. For similar reasons the sharp differentiation in area per man between virgin and cut-over areas indicated in item (1) cannot always be attained in practice. The point is, however, that a more intensive organization must be assured for cut-over areas, even though they intermingle with virgin timber. Because of the increased growth of grass, weeds, and saplings after cutting, the special hazard is not removed entirely with the disposal or rotting of the slash, and therefore an intensive organization must be continued for 20 or 30 years, at least.

Items (2) to (8) are obviously in the nature of special precautions in connection with lumbering operations and cut-over lands. Except for dead-snag felling, which on the Colorado Plateau costs about 30 cents an acre, it is impossible to make an accurate estimate of the cost of these items on a volume or acreage basis. As a matter of fact, they are offset very largely, if not entirely, by corresponding decreases in the costs to operators of fire suppression, loss of equipment, logs, etc. All too frequently in past years individual forest fires have cost lumbermen hundreds if not thousands of dollars. In more recent years, due mainly to the above measures, fire losses on the national forests have been very light.

SLASH DISPOSAL

As previously stated, the principal purpose of slash disposal is to facilitate the control of fires. With fire control as the primary object the following measures are necessary. Such further practices in connection with slash as are principally for the silvicultural welfare of the forest will be covered under Measures Necessary to Produce Full Timber Crops.

BLACK HILLS

Pile and burn all slash, except on steep slopes and in open stands on south and west exposures, where it should be lopped and scattered.

SOUTHWEST

Pile and burn all slash on fire lines 100 to 200 feet wide and so located as to break up the cut-over area into blocks of not more than 160 acres. Also, pile and burn slash on areas of special fire hazard as defined under Fire Protection, item (8).

It is not the function of this bulletin to give a detailed treatise on piling and burning slash. At the same time, without setting hard and fast rules as to details, it may be helpful to record as guides certain general principles drawn from Forest Service experience (fig. 15).

One of the essentials is prompt piling. Slash handles more easily and can be piled better and more cheaply while green. When dry, the needles shake off and the protective measure thereby loses much of its effect. Moreover, if promptly piled the slash settles into a compact mass and is ready to burn at the first favorable opportunity. The Forest Service aims to have slash piled within 6 weeks after cutting unless prevented by deep snow. Promptness is especially essential on fire lines and areas of extraordinary hazard.

It is not practical to pile and burn the large pieces. The usual practice is to trim up and throw aside stems more than 4 inches in diameter.

Piles should be made as compact and as nearly tepee-shaped as possible. Large piles, from 6 to 8 feet in diameter and from 4 to 6

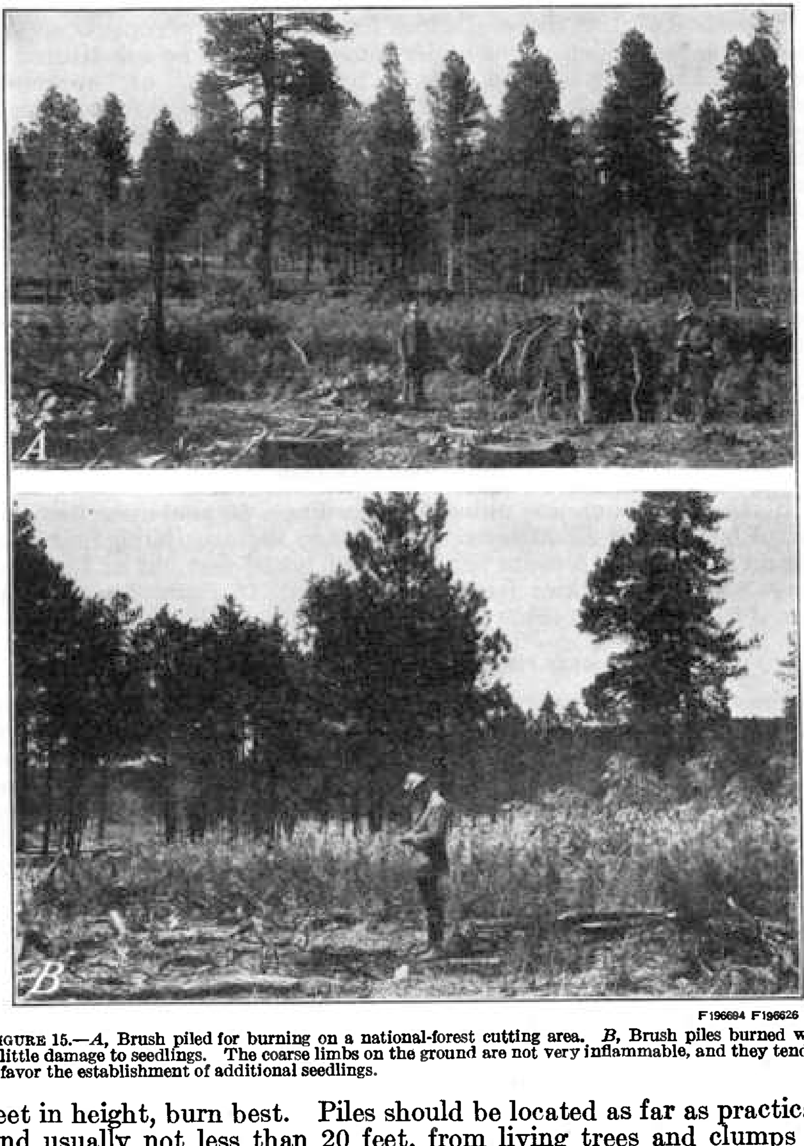

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FIGURE 15.—*A*, Brush piled for burning on a national-forest cutting area. *B*, Brush piles burned with little damage to seedlings. The coarse limbs on the ground are not very inflammable, and they tend to favor the establishment of additional seedlings.

feet in height, burn best. Piles should be located as far as practical, and usually not less than 20 feet, from living trees and clumps of saplings, or else size of piles should be kept down sufficiently to prevent damage to the remaining stand.

Burning can be done most effectively and safely with snow on the ground. The next choice is during rainy periods. Where it is urgent to clear promptly areas of special hazard, night burning may be practiced if conditions are not favorable in the daytime. A special effort should be made to avoid letting dry slash lie through the dry early summer. Piles so located as to threaten excessive damage should be left unburned. The special precautions that are needed to keep fires within control may require patrol for a week or more after burning to prevent spread of fire from smoldering logs or litter.

A method of slash disposal which from limited experiments appears promising and which might under some conditions be substituted for piling and burning is what may be termed "green" or "swamper" burning. The slash as it is cut from the trees is thrown directly upon stationary fires. This method, of course, is usable only when the ground is snow-covered or quite wet. At such times the results are a cleaner disposal and less damage than under the usual method of piling and burning.

In the Black Hills effective slash disposal is an indispensable means of fire control and is believed to be the crucial item in keeping forest land productive. The Homestake Mining Co., which is the largest owner and operator of private timber in the Black Hills, practices piling and burning uniformly. It is required on Forest Service timber sales and on State sales. In the Southwest there is no slash disposal on private lands.

It is estimated that the requirements will cost [10] as follows:

PONDEROSA PINE TYPE

Black Hills (complete piling and burning), 50 cents per thousand board feet cut, or $2.50 per acre; Colorado Plateau (piling and burning on fire lines), 15 cents per thousand board feet cut or $1.05 per acre; southern Rockies (clearing fire lines), 15 cents per thousand board feet cut, or 75 cents per acre.

DOUGLAS FIR AND ENGELMANN SPRUCE TYPES

Since for these types piling and burning on fire lines is uniform for all regions, differences in cost will be determined largely by the amount of debris to be handled. The figure of 15 cents per thousand board feet of total cut furnishes a fair basis for calculation. The cut per acre will vary from 5,000 board feet in the southern Rockies to 20,000 board feet in the Sacramento Mountains, and the corresponding costs will vary from 75 cents to as high as $3 per acre.

CUTTING [11]

The primary purpose in regulating cutting as a minimum requirement is to preserve seed trees where these are needed and so avoid excessive denudation (fig. 16). Where complete advance reproduction exists and can be preserved through the logging operation, seed

[10] The various items of cost given in this bulletin are based on wage scales and other price trends prevailing before 1930.

[11] As this bulletin goes to press, a modified set of minimum requirements is being put into effect under the provisions of schedule C of the lumber code. The main difference between the two sets of requirements is that those here outlined specify that seed trees must be of good form, while the rules prescribed under schedule C permit them to be of low value for lumber, provided the crowns are thrifty. In drafting of code requirements under schedule C it was necessary to take into account the fact that the code deals with timber operators as distinguished from landowners. Since few of the operators in the Southwest own the land on which they are cutting, and most of those operating on private land are under contracts which call for removal of all merchantable timber, it seemed unjust to demand that they sacrifice the values represented by seed trees of high merchantable quality. Obviously the direct cost of minimum requirements should be borne by the landowner who will reap the benefits.

trees are obviously unnecessary. Such is usually the case in the Black Hills. In the Southwest, seed trees are generally needed, although in some sections the presence of fairly complete advance reproduction makes it possible to reduce the number or the size of the seed trees left. As already pointed out, trees below a certain size, varying somewhat with the species and the region, cannot be relied upon to produce enough seed for natural reproduction on a large scale. The seed trees, if of the right type, will contribute substantially to the next cut, and for this reason it is important to select good, thrifty trees. Such trees will as a rule pay their way by increased growth in addition to seed production, whereas poor trees are likely to be a total loss. The major item in the second cut will be the young trees just below merchantable size at the time the first

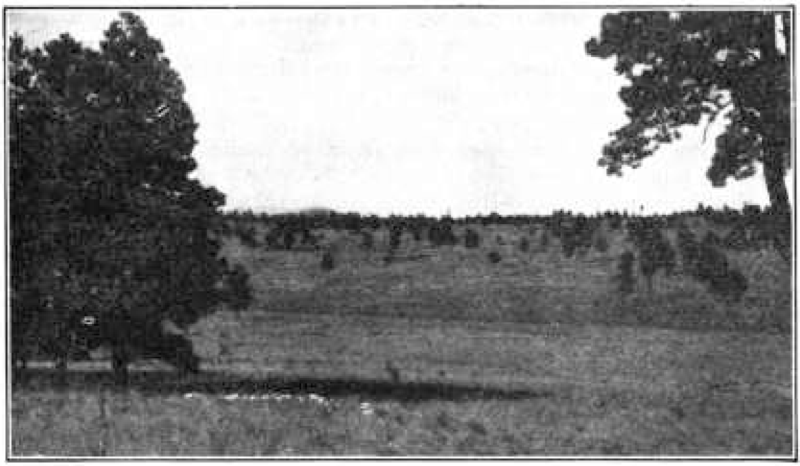

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FIGURE 16.—Ponderosa pine area 40 years after logging. The trees left were too few and too small to provide adequate seed for reproduction; some are now of seed-bearing size and a few seedlings are starting. At least 100 more years must elapse before a second cut can be made.

cut is made. The number of these will depend on the character of the original stand, and also upon the type of cutting. If the operation removes only saw timber, more of the fairly large-sized immature trees will be left than if ties, stulls, and props are taken. This affects not only the residual stand but also seed production, because, although individual small trees bear only a small quantity of seed, a large number, if well distributed, may become an important factor in reproduction:

The minimum requirements for different forest types, regions, and conditions, and the estimated costs, including stumpage and increased depreciation and spur charges, are as follows.

PONDEROSA PINE TYPE

BLACK HILLS

(1) Advance reproduction of at least 500 established[12] and well-distributed seedlings, saplings, and poles[13] per acre present: No restrictions.

[12] Seedlings are not considered established until they are about 1 foot high.
[13] The term "poles" is used to designate young trees 4 to 12 inches d. b. h.

(2) Advance reproduction below the above specifications: Leave 4 seed trees per acre more than 14 inches d. b. h. (volume about 500 feet board measure per acre).

In the Black Hills it is estimated that at least 90 percent of the area will fall under condition 1. Reproduction is easy to get and is nearly always abundant in uncut stands. In fact, reproduction is often considered too dense for good development.

SOUTHWEST

(3) Advance reproduction of at least 200 established and well-distributed seedlings, saplings, and poles per acre present:

(*a*) Leave all thrifty trees below 16 inches d. b. h. (volume about 165 feet b. m. per acre); or

(*b*) Leave 2 seed trees per acre over 17 inches d. b. h. (volume about 500 feet b. m. per acre).

(4) Advance reproduction as above described not present:

(*a*) Leave all thrifty trees below 21 inches d. b. h. (volume about 550 feet b. m. per acre); or

(*b*) Leave 3 seed trees per acre over 17 inches d. b. h. (volume about 900 feet b. m. per acre).

In the Southwest, condition 3 will apply to most of the ponderosa pine type, but important exceptions may be found where grazing and fire have not been adequately controlled. The alternatives provided are designed to permit either an exclusively saw-log operation by cutting to a diameter limit, or the cutting of ties, stulls, and props and restocking by seed trees. According to Coconino National Forest stand tables, cutting to a 15-inch diameter limit would leave 12.3 trees per acre from 6 to 11 inches d. b. h., and 2.8 trees 12 to 15 inches d. b. h., or a total volume of 165 feet board measure. Tie, stull, and prop cutting removes practically everything down to 7 inches. The 2 seed trees required under this alternative would in practice range from 18 to 22 inches, inclusive.

Corresponding alternatives are provided in condition 4. The essential difference is that there is less advance reproduction and therefore better provision for seed is required. The Coconino stand tables indicate that when the cutting is to a 20-inch diameter limit there will be left about 12 trees 6 to 11 inches d. b. h. and 5 trees 12 to 20 inches, the latter class having a total volume of about 550 board feet. When 3 seed trees over 17 inches are to be left, the actual diameters will range from 18 to 25 inches and the total volume will be about 900 board feet. The first alternative will obviously be preferred by the saw-timber operator on account of the smaller volume left, especially in the larger diameters. At the same time, the land remains in fairly good condition because the deficiency in large seed trees is in a measure offset by the larger number of trees between 6 and 18 inches d. b. h., many of which will attain effective seed-bearing size within 20 years.

A comparison of cutting requirements under different conditions at once reveals the great advantage to the operator of having his lands well stocked in advance of cutting. Since the requirements under (3*a*) and (3*b*) for the Southwest presuppose a rather low average standard of advance reproduction, it follows that on areas of good advance reproduction the requirements might be lowered appreciably, thus reducing the investment in seed-tree stumpage to a low figure.

Private owners who wish to leave their lands in productive condition might well consider postponing cutting until present protection measures have resulted in the establishment of advance reproduction. The difficulty is that it will take from 10 to 20 years to get advance reproduction, and the private owner may not be able to defer so long the conversion of salable stumpage into cash.

DOUGLAS FIR TYPE

Douglas fir stands differ from the typical stands of ponderosa pine in that they are denser, usually having larger numbers of poles and immature trees. For this reason, fewer large seed trees are required. Where the less valuable white fir occurs in mixture, there is a tendency to leave seed trees of this species rather than of Douglas fir. This practice tends to encourage white fir reproduction at the expense of Douglas fir, and although the cutting restrictions do not prohibit this, the owner should be aware of the consequences. The requirements under different conditions of advance reproduction and for removal of different kinds of material are as follows:

(1) Where there is advance growth of more than 500 established and well-distributed seedlings, saplings, and poles per acre, everything above (not including) 12 inches d. b. h. may be cut. This would leave some 40 trees per acre above 4 inches d. b. h. and about 8 trees per acre above 10 inches d. b. h., containing about 200 board feet.

(2) Where advance growth as above described is absent or deficient, two alternatives are provided:

(*a*) All trees above (not including) 16 inches d. b. h. may be cut. This will leave from 15 to 20 trees per acre over 10 inches d. b. h. with a volume of about 800 board feet; or

(*b*) Two seed trees over 17 inches d. b. h. per acre should be left and all other trees above (not including) 12 inches may be cut. The volume of seed trees and others above 10 inches d. b. h. will be about 800 feet board measure.

Condition 2 is more frequently found within the border region, particularly the Sacramento Mountains, than elsewhere. Consequently the retention of seed trees will be particularly necessary there.

Even with seed trees, a minimum diameter limit of 12 inches, which will interfere somewhat with the cutting of hewn ties, is prescribed to prevent, by excessive cutting of small material, the complete removal of the forest cover, which must be avoided in a type which occurs on steep slopes and is important for watershed protection. An ample supply of mine props and stulls may be obtained from tops in this and in other forest types. It should be added that if the owner is in a position to execute thinnings by judicious removal of stems below the diameters indicated, this is very much to be desired. Such removal, however, should be done only under the direction of a forester.

As in the case of ponderosa pine, the cost of leaving seed trees involves both the stumpage value of the trees and the resultant increased depreciation and logging spur charge, but this is similarly offset to some extent by the return from these trees when they are harvested in a second cutting.

ENGELMANN SPRUCE TYPE

The almost universal presence of young growth in the merchantable stands of this type and the habit which both Engelmann spruce and corkbark fir have of producing seed while still small, preclude the need for retaining merchantable trees for seeding. Seed trees would be very difficult to maintain because of the susceptibility of these species to windthrow. It is, however, quite important to maintain a forest cover on the steep slopes characteristic of this type. After seedlings are a foot high they do well in full sunlight.

A diameter-limit method of cutting best fits the case and may be stated as follows: Retain all trees up to and including 12 inches d. b. h. The volume left under this limitation will be almost negligible.

This method is much less conservative than current Forest Service practice, which has as its object the growing of the maximum volume of timber. As stated of Douglas fir, properly directed thinnings, whereby surplus trees of small sizes are removed, are desirable.

LOGGING

The primary purpose of logging restrictions is to prevent unnecessary damage to advance reproduction, seed trees, and young trees normally left because they are of unmerchantable size. Carelessness in the use of steam skidders and tractors and in the felling of trees may destroy a large proportion of the immature growth which, if preserved, makes a creditable contribution to the future forest and in many places is sufficient for a cut in about 75 years. It is recognized that some damage of this sort cannot be avoided, but on the other hand most of the damage in unregulated logging is due to lack of care and foresight on the part of the operator.

No specific limitations are necessary except for steam skidders and tractors. Fortunately, the donkey engine has not been introduced in pine logging in the region nor is there likelihood that it will be. The steam skidder in use is the two-line ground type which reaches out to a maximum distance of 2,200 feet from the track. Steam skidding in pine forests is practical only on the Colorado Plateau and has been used thereon to a limited extent. For this type of skidder, the following measures should be observed:

(1) Ground lines only may be used. These shall be run at right angles to the track.

(2) The skidding trails shall be parallel to each other and must not converge as they approach the skidder. The distance between the skidder trails may vary inversely with the volume of timber cut per acre.

(3) Logs may be skidded into the trails by horses, not by side-haul lines.

(4) Every reasonable care must be taken to prevent unnecessary damage to reproduction.

These measures, conforming with Forest Service practice, have been found after several years' experience by large operators to be practicable. So restricted, steam skidding is not a bad thing silviculturally. Skidder trails, where the soil is stirred up and grass removed, favor reproduction and also make fair fire lines. On steep slopes, slash should be thrown into the trails to prevent erosion.

Portable and semiportable overhead Lidgerwood skidders have been used in Douglas fir logging in the Sacramento Mountains. While under the best practice Lidgerwoods may be ruled out, it is not believed justifiable to do so unless the aim is to practice better forestry than is required merely to keep the lands productive. The necessary precautions may be stated as follows:

(1) In using steam skidders, irrespective of type, the skidder trails must be at least 500 feet apart at their outer extremities.

(2) Logs must be pulled into the skidder trails, either by horses or by machinery, at right angles to the trail.

An additional word should be said about tractor logging, which has come into general use during recent years and promises to become the prevailing method. In the hands of a thoughtless driver, the tractor is capable of great destruction. Crashing through thickets of saplings or small poles can be avoided to a great extent by laying out routes of travel in advance. Swinging logs sidewise through groups of young growth, and skidding logs from which the limbs have not all been removed should be prohibited.

It is not believed that the above measures will generally entail appreciable added expense over an unrestricted system in this region.

GRAZING

Control of grazing is necessary not only to protect forest reproduction, but also to insure maximum returns from the forage crop. Investigations by Hill (*5*), Cooperrider,[14] and others in the Southwest point to overgrazing [15] rather than grazing per se as the main cause of damage to forest reproduction by livestock. That reduction of stocking is effective has been demonstrated on a large scale on the Coconino, Kaibab, and Sitgreaves. Destructive grazing damage that had continued over a long period of years was checked on extensive areas by heavy reductions of cattle and sheep in and about 1926. On many allotments the reductions expressed in animal-months were as high as 50 percent or even more. The decrease in numbers was accompanied by a shortening of the grazing season, and by fencing and other measures which resulted in better distribution of stock. Although damage still persists in some localities, conditions in the region as a whole have been greatly improved. It cannot be said that range management such as required in the interest of livestock production alone will insure adequate protection to forest reproduction; but the results will in most instances compare favorably with other protective standards in the type of forestry contemplated under Minimum Measures Necessary to Keep Forest Lands Productive. The most essential precautions may be briefly stated as follows:

The range should be stocked conservatively (with cattle or sheep, but not both on the same area), adjusting the number of animals to the forage produced in poor rather than good years. If pine seedlings are being browsed over extensive areas, the number of animals or the length of the grazing season should be substantially decreased. Localized damage is usually caused by poor distribution of stock. Concentration of cattle can be lessened by providing adequate water

[14] The results of these investigations by C. K. Cooperrider are not yet published.

[15] Overgrazing, as the term is used in this bulletin, is defined as that use by grazing animals which impairs the sustained productivity of the range. It involves overstocking, incorrect seasonal use, improper class of stock, and local concentration of stock.

and salt at suitable intervals. Sheep should not be bedded on the same ground more than one night in any year. Trailing repeatedly over the same ground should be avoided. The dates for opening and closing the range should be determined by the condition of the forage, and therefore will vary somewhat with localities and years from the average dates of June 1 and October 1; in some instances the opening date could well be deferred until the summer rains are in progress.

SUMMARY OF COSTS

Table 5 summarizes the costs of the prescribed measures in the ponderosa pine and Douglas fir types, insofar as it is practical to estimate them. As in other instances, price levels prior to 1930 have been used. To these figures should be added the annual cost of about 1 cent per acre for fire prevention and 3 mills per acre for fire suppression. In the Engelmann spruce type the only expense, except the above items for fire prevention and suppression, is for brush disposal on fire lines, which will amount to about 15 cents per thousand board feet of total cut.

TABLE 5.—*Cost per acre of minimum logging requirements*

PONDEROSA PINE TYPE

Subregion and cutting requirement [1]	Cutting [2]	Slash disposal	Total
Black Hills:			
Requirement (1)	----------	$2.50	$2.50
Requirement (2)	$2.35	2.50	4.85
Colorado Plateau:			
Requirement (3*a*)	.68	1.05	[3] 2.03
Requirement (3*b*)	2.12	1.05	[3] 3.47
Requirement (4*a*)	2.35	1.05	[3] 3.70
Requirement (4*b*)	3.40	1.05	[3] 4.75
Border and southern Rockies:			
Requirement (3*a*)	.71	.25	.96
Requirement (3*b*)	2.22	.25	2.47
Requirement (4*a*)	2.46	.25	2.71
Requirement (4*b*)	4.03	.25	4.28

DOUGLAS FIR TYPE

Subregion and cutting requirement [1]	Cutting [2]	Slash disposal	Total
Colorado Plateau:			
Requirement (1)	.75	1.05	1.80
Requirement (2*a*)	2.90	1.05	3.95
Requirement (2*b*)	2.90	1.05	3.95
Southern Rockies:			
Requirement (1)	.70	.75	1.45
Requirement (2*a*)	2.80	.75	3.55
Requirement (2*b*)	2.80	.75	3.55
Border:			
Requirement (1)	.65	2.70	3.35
Requirement (2*a*)	2.60	2.70	5.30
Requirement (2*b*)	2.60	2.70	5.30

[1] See pp. 42–46.
[2] Includes value of stumpage at $3 per M feet b. m. for ponderosa pine and $2 per M for Douglas fir; also increased rate of depreciation and spur charges due to a reduced cut per acre, estimated at $1.25 to $1.70 per M feet for the pine type and $1.50 to $1.70 for the fir type.
[3] Includes 30 cents to cover snag-felling.

RETURNS

The yields to be expected under the measures which have been prescribed will depend greatly upon the condition in which the forest is left by the first cutting and upon the success attained in protective measures. It should be remembered that in a scheme of minimum requirements the primary purpose is to avoid forest destruction and that the time that must elapse before a second crop can be cut is a secondary consideration and more or less speculative. Trees between 8 and 20 inches in diameter increase after cutting at a rate of 1 to 1.5 inches in 10 years. Whether or not a logging operation is commercially feasible, however, depends upon the numbers as well as the size of merchantable trees per acre. Usually only a few trees larger than 14 inches d. b. h. will be left, and therefore sufficient time must elapse for adequate numbers of poles to grow to merchantable size.

Where considerable numbers of poles remain after cutting, a second crop may be removed in from 40 to 100 years, depending on the species, the site, the amount of material remaining in the higher diameters, and the size of product desired. Under average conditions ties may be cut in 40 years and saw timber in 60 to 100 years. In the Black Hills and on the best sites of Douglas fir and ponderosa pine in the Southwest, the above periods may be decreased somewhat. Diameter growth is generally slow in the Engelmann spruce type, except when adequately thinned, because of the habit of the species in this type of growing in extremely dense thickets.

If the first cutting leaves fair advance reproduction in the form of seedlings and saplings, but few poles, the second cut will recede in the Southwest to about 80 years for ties and 150 years for saw timber, with possibilities of shortening these periods by 10 to 20 years in the Black Hills and on the better Douglas fir and ponderosa pine sites of the Southwest.

Returns from areas lacking advance reproduction and pole growth at the time of cutting are difficult to estimate because of the uncertainty of restocking. Allowing 40 years for this process and 150 years for growth from seedling to merchantable size, the total period becomes 190 years. This is probably the lowest period that should be assumed on a saw-timber rotation in the Southwest, where considerable time must be allowed for restocking. Ties might be obtained in as low as 120 years after the first cut.

Yields in volume are even more speculative than the time required to produce trees of merchantable size. Assuming that under minimum measures required to maintain a forest cover the stands will seldom be more than half stocked and usually below this standard, the yields will be low. For the periods which have been indicated as necessary to attain the diameters required for saw timber, the acre yields in the three types may be estimated as follows: Ponderosa pine type, 3,000 to 5,000 feet board measure; Douglas fir type, 4,000 to 8,000 feet board measure; Engelmann spruce type, 4,000 to 6,000 feet board measure.

MEASURES NECESSARY TO PRODUCE FULL TIMBER CROPS

The measures necessary to produce full crops of timber are in a general way the same as those outlined under Minimum Measures to Keep Forest Lands Productive, except that they go farther and contemplate more intensive application. Under the measures representing minimum requirements, ultimate maximum yields and public welfare are subordinated to immediate returns to the owner. A program providing for the growing of full timber crops in this region must subordinate direct and immediate income to ultimate returns both direct and indirect, viewed from the standpoint of public interest.

Except for a relatively small area in the Black Hills, it is not contemplated that private enterprise will engage in forestry to any great extent in the region covered by this bulletin, and for this reason the discussion in the following pages is directed primarily to those responsible for or interested in the management of forest lands in public ownership. The standards here advocated aim to go a step beyond present practice in the national forests, keeping in mind present economic limitations but at the same time anticipating a gradual removal or modification of these limitations. It is even possible that future economic conditions will justify standards of silviculture on the most accessible lands higher than those contemplated in this bulletin.

A great opportunity for improvement over past practice lies in better stocking of the forests. Full timber crops cannot be grown on land that is only partially utilized. Forests throughout the region are bearing light crops because they are or have been understocked. Forest management is handicapped because the stands with which it has to deal are, if not actually understocked, made up largely of trees which are either too old or too young to contribute effectively to the volume increment. One of the most fruitful lines of endeavor in silviculture now is to manage uncut forest with a view toward encouraging advance reproduction and building up the younger age classes so that when the mature timber is harvested there will be left a thrifty young growing stock properly balanced as to age classes. When it is considered that large areas will not be cut within 50 years the excellent opportunities for this kind of improvement are apparent.

The factors which man can control in the production of larger crops of timber are fire, cutting, slash disposal, logging, grazing, insects, mammals and birds, and diseases. Measures to control these factors will be discussed in the following pages. In applying these measures it should be borne in mind that successful forestry, like any other industry, calls for more than perfunctory compliance with rules and regulations. It calls for constant observation and study with a view toward meeting every contingency in the right way and at the right time. In growing crops under a great diversity of conditions, and under many uncertainties of climate and biotic influences, the best laid plans will need to be modified from time to time. Moreover, our knowledge of the requirements of forest trees and stands is far from complete, and any program of forest management must provide adequately for research. All of this presupposes a scientifically trained and well-organized personnel.

FIRE PROTECTION

The standards of and the organization for fire protection outlined under Minimum Measures to Keep Forest Lands Productive are essentially those of the Forest Service in the southwestern region at the present time. Full compliance with those measures should reduce the size and number of fires to a point where they will cease to be a serious limiting factor in forest production. It is feared, however, that an agency whose aim is merely to maintain some sort of forest cover would fall far short of the required suppression standards. Experience in the Forest Service up to a few years ago showed that a considerable percentage of the large fires was attributable to avoidable errors on the part of individuals directly responsible for fire suppression. Gradual tightening up of the organization, better trained personnel, improved equipment and transportation facilities, and a better understanding of fire problems have brought about marked improvement and may be expected to bring still further progress. It is only this highly developed type of organization that should be considered in a program which aims at the production of full timber crops.

Reference has already been made to the increased fire hazard due to the presence of slash after cutting. As large continuous areas are cut over the difficulty of controlling fires under extremely unfavorable weather conditions will increase. To avoid the possibility of extensive conflagrations, it may become advisable to break the continuity of slash areas by making an intensive clean-up of slash on extra-wide fire lines. If reproduction is successful, the accumulation of leaf litter and the susceptibility to crown fires in the sapling and pole stages will constitute an added hazard. Under these conditions even the complete removal of slash may not create adequate fire lines. This is a problem to be worked out by investigation and large-scale experimentation in administrative practice.

A factor to be counted upon increasingly as time goes on is the cooperation and good will of forest users and the general public. These benefits will be realized in much higher degree, however, under high than under low standards of forest production. Notwithstanding an improved public attitude, both education and law enforcement must be important parts of a fire-protection program.

CUTTING

In the presentation of minimum measures for keeping forest lands productive the importance of natural reproduction has necessarily overshadowed all other silvicultural aims. In a program which contemplates growing full timber crops, even greater precaution will be taken to guard against deficient regeneration; to this end advance reproduction will be a primary objective in the management of virgin forests, and in cutting more and larger seed trees will be reserved than are called for under minimum requirements. No less emphasis must be placed on the development of stands after the reproduction stage is past. Whether needed for seed production or not, trees will be left for growth to provide for future cuts at specified intervals. In localities where reproduction is assured without special provisions, leaving a good growing stock becomes the primary consideration in marking, or designating trees to be removed. This is also a major objective on areas where reproduction is sought, and consequently trees are here reserved from cutting for the dual purpose of reproduction and increment.

SILVICULTURAL SYSTEMS

The silvicultural system or standard method of cutting commonly practiced by the Forest Service in the ponderosa pine type is what is known as the group-selection system. As the name implies, it is a selective or partial cutting system based on the conception that the forest is made up of even-aged groups, which is the characteristic condition in the major portion of the Southwest where the system was developed (fig. 17). The first step is to mark for removal all overmature, diseased, defective, or otherwise undesirable trees. The mature class is also removed except as individual trees are retained for seed production or to avoid large vacant spaces (fig. 18). The number needed for seed obviously depends on the presence or absence of adequate advance reproduction. Usually entire groups of overmature and mature trees are cut and the individuals reserved for

FIGURE 17.—Ponderosa pine in northern Arizona. *A*, Typical group arrangement of age classes. In applying the group-selection method, the group of large trees in the left foreground would be felled except for 1 or 2 seed trees; the group of blackjacks in the background would be left standing. *B*, A similar stand after cutting. The large trees in the foreground are seed trees; those in the background are mostly blackjacks.

seed are, so far as possible, such as have grown in the open or on the edges of the groups. All blackjacks and intermediates are left except where removal will improve the stand. In dense pole stands, thinnings are executed to the fullest extent that market conditions will permit.

A scattered seed-tree method has been tried experimentally on the Coconino National Forest with good results as to reproduction. An average of 2.5 selected seed trees per acre between 21 and 30 inches

d. b. h. were left as evenly distributed as possible. All other trees above 11 inches d. b. h. were cut. Although the results were generally good, indications are that approximately one more seed tree per acre would have given more uniform distribution of seedlings. As it is, reproduction about equals that where the standard group-selection method was employed. The obvious objection to the scattered seed-tree method is that it removes too much of the growing

FIGURE 18.—*A*, Immediately after cutting by group-selection method in 1907. Groups of blackjacks in the background; large yellow pines left to seed up open spaces. *B*, The same view 20 years later. Most of the ground is now stocked with seedlings 11 to 16 years of age. The broken top in the foreground is from the tree at the extreme right. Note also the persistence of dead branches on this tree.

stock in the blackjack and intermediate classes which by the group-selection method are left to supply the second cut.

The selection of trees to cut or leave can best be done by observation, assuming adequate experience and silvicultural training on the part of the forest personnel. An experienced timber marker knows at a glance to what general age-class a tree belongs. He knows from the size, form, density, and general appearance of the crown whether the tree is capable of rapid growth when given adequate growing space by removing competition. He also considers seeding capacity, whether the tree is a bad risk from the standpoint of wind and lightning, and whether its increment will be in material of high or low grade.

Essentially the same silvicultural practice has been employed in the Douglas fir and Engelmann spruce types as in ponderosa pine. The main difference is that more trees are left in fir and spruce than in pine stands. The age classes are much the same and commonly occur in groups, very much as in a ponderosa pine forest, although the groups tend to coalesce or sometimes give way to even-aged stands of considerable extent. These even-aged stands constitute a problem, particularly in spruce, because they are usually dense and have a tendency to become deadlocked, slowing down the growth of the entire stand or group. Where there is a market for ties and mine props the situation is improved somewhat, although the groups in need of opening up are mostly below the size, and mine props have a very limited demand. Thinnings on a crop-tree basis may afford a solution.

Extensive areas of Douglas fir, white fir, alpine fir, corkbark fir, and Englemann spruce in the high mountains are, because of transportation difficulties, better adapted to a tie crop than to a sawtimber crop. Hewn ties are more readily made from trees between 11 and 15 inches in diameter than from those of larger dimensions, and this tends to influence the cutting toward a diameter limit. Where natural reproduction comes easily ties may be the best crop, but provision should be made for utilizing the larger trees in the form of lumber or sawn ties. Even on a tie rotation, it would probably be necessary in most sections to grow some trees larger than hewn-tie size in order to insure an adequate seed supply. At the present time some of the species are not accepted for railroad ties, but it is probable that in the course of time the objections to these species can be removed.

SECURING REPRODUCTION

A program of intensive forestry must assume advance reproduction to the fullest extent that the density of the stand will permit, since without such reproduction considerable portions of the ground will lie idle anywhere from 10 to 30 years after cutting. But it is equally essential that every silvicultural program provide adequately for reproduction after cutting. Even though all available space is occupied at the time of cutting by seedlings or young trees, so that substantial progress has been made on the next rotation, the removal of dense groups of timber may leave considerable patches unstocked, and additional strips and patches may be denuded by the logging operation (fig. 19). Moreover, even under the best practice, there will occasionally be areas on which advance reproduction for some reason or other has failed, as, for instance, when a ground fire has swept through. Deferred cutting, to allow reproduction to be completed, is advisable if the areas are large; but such delay is not always practicable.

Whether seed requirements will be met automatically by the trees left for future growth, or whether additional seed trees are needed, is a matter which the forest officer must decide for each area individually. It has been determined on the Colorado Plateau that, where advance reproduction is lacking, four seed trees of more than 20 inches d. b. h. per acre are required. Under conditions of partial advance reproduction, the number may be reduced in proportion to the area in need of stocking. Similar requirements would apply to southern Colorado. In northern New Mexico and elsewhere in the Southwest where conditions are very favorable for reproduction, the minimum diameter may be reduced to 18 inches. In the Black

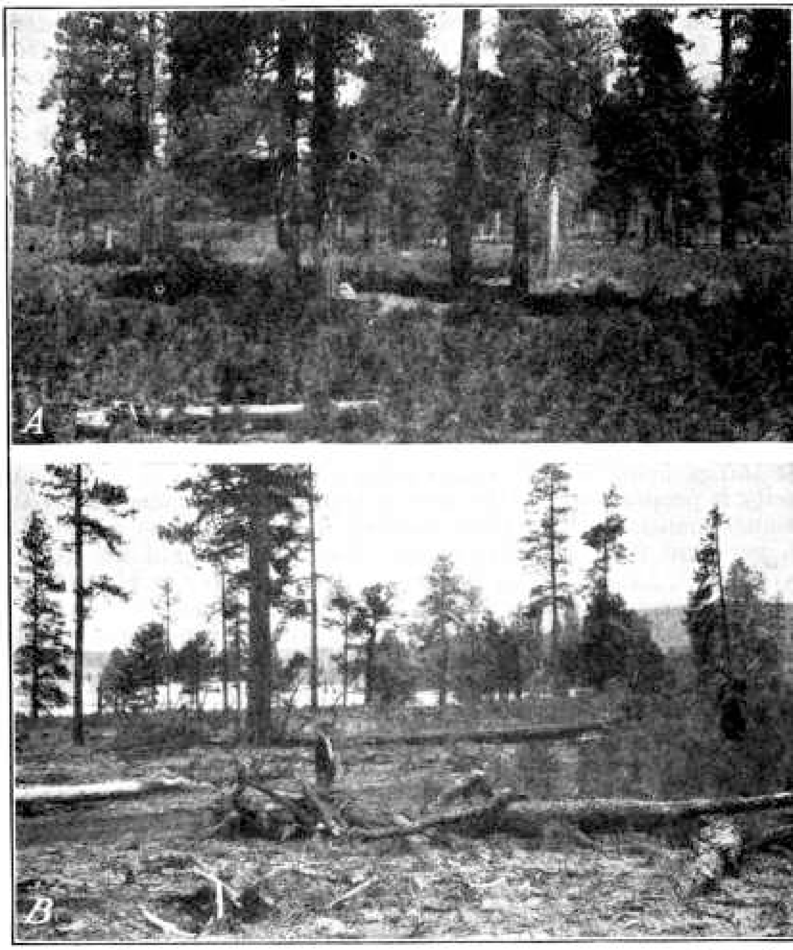

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FIGURE 19.—*A*, Advance reproduction in uncut stand of ponderosa pine; *B*, a stand in which advance reproduction was considered good before cutting but in which cutting left large vacant spaces where tree groups formerly stood. The large trees were left to seed up these spaces.

Hills, seed trees as such are required only in exceptional instances, as on some rather extensive limestone areas where stands have been thinned by bark beetles and reproduction has failed. Since these failures are plainly not due to a lack of seed they do not furnish a clue as to the number and size of seed trees required.

Selected seed trees should be located, so far as possible, with reference to areas in need of restocking. Large trees scatter seed in effective quantities over distances of 100 to 200 feet, depending on wind direction and velocity. A single tree will not usually cover adequately a circle of this radius, but it is reasonably certain that if 3 or 4 seed trees per acre are spaced more or less uniformly they will cover practically all of the area effectively in the course of several weeks' seed fall.

In the Douglas fir and Engelmann spruce forests the number of immature trees of seed-bearing size is usually sufficient so that if adequate provision is made for a balanced growing stock and for protection of the soil, few seed trees, as such, need be left. As a general guide, the minimum number in the Douglas fir type should be 6 trees over 16 inches d. b. h., and in the Engelmann spruce type 8 trees over 14 inches d. b. h. In the border region, where Douglas fir tends to large dimensions, the minimum should preferably be raised to 18 inches d. b. h. If the stand is deficient in poles and saplings, the above numbers may have to be increased in order to provide adequate cover.

From all standpoints, considering seed yield in relation to wood capital invested, growth possibilities, and susceptibility to loss, ponderosa pine between 20 and 25 inches in diameter and somewhat smaller Douglas fir and Engelmann spruce are regarded as the most efficient seed producers. If the desired number of healthy, full-crowned trees are not to be found within a specified diameter range, it should be realized that diameter is after all only a guide and not a final criterion. An experienced timber marker selects seed trees mainly from the size and appearance of the crown, knowing that, other things being equal, seed-bearing capacity as well as growth capacity is proportional to the area of exposed leaf surface and space for root expansion. The same criterion determines the number of trees per acre that he must leave. Each tree should be studied individually. In practice, a few seed trees of ponderosa pine will be up to 30 inches in diameter and others below 20 inches.

In overmature or diseased stands of ponderosa pine there will be areas on which the required number of good seed trees is not available, but often this can be compensated by increasing the quota within effective seed-carrying distance, or not to exceed 300 feet. A compromise in numbers is preferable to leaving trees that are plainly on the decline and cannot, therefore, contribute much to the yield of seed or timber. This problem becomes particularly troublesome in stands infected with mistletoe, since infected trees not only decline rapidly but spread the infection to healthy young trees. Complete eradication of mistletoe may mean practically clear cutting, including trees below merchantable size. It is important to know that freedom from mistletoe and resistance to its action is most likely to be found in large, mature trees. Thus far, complete eradication of mistletoe has not been attempted because of the expense of cutting unmerchantable material and the risk of denuding areas to such an extent that they will not restock. This subject is treated more fully under the section on control of diseases, page 68.

CARE OF YOUNG STANDS

Having restocked a cut-over area, the next consideration is such care of the young stand as will encourage rapid growth and good form. Assuming protection against destructive agencies, the first essentials are proper spacing and the maintenance of good soil condition.

It is a recognized principle in silviculture that dense stocking in the early stages of a stand is necessary to produce straight, clean stems. Open-grown trees tend to produce large diameters, but with rapid taper and excessive limbiness. These characteristics are developed to the extreme in ponderosa pine on the Colorado Plateau. If limbs are allowed to grow large enough to develop a substantial core of heartwood they persist indefinitely. Photographic records of dead limbs 2 to 3 inches in diameter on ponderosa pine trees near Flagstaff show no visible change after 20 years (fig. 18, *B*). It is too much to expect that even close spacing will promote natural pruning to such an extent as to produce clear stems in young trees; but if the

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FIGURE 20.—Open stands in which limbs are persisting. Trees grown in this manner form knotty, tapering trunks of low market value.

lower limbs die while less than an inch in diameter a fair grade of lumber will result. If they are allowed to attain a diameter of over 2 inches it is safe to say that the lumber will be mostly cull, according to present standards of grading (fig. 20).

If young stands are open enough to permit luxuriant ground vegetation, the soil moisture available for the trees is reduced by the amount used by this vegetation. An ideal condition is one in which the trees are close enough to permit only sparse undergrowth and to form a uniform carpet of needles (fig. 21). The needle litter promotes percolation of water (*9*) and is one of the most effective of erosion preventives.[16] It is not to be expected that the stand will everywhere be dense enough to maintain a closed canopy, especially in pine; but unless the openings are more than 50 feet in diameter, they will eventually be occupied by tree roots and needle litter from surrounding trees, which, supplemented by herbaceous or shrubby vegetation, will provide adequate soil protection if grazing is not too heavy.

Various attempts have been made to establish a quantitative standard of satisfactory stocking. Obviously, the number of trees per acre does not adequately define the standards unless distribution also is indicated. Moreover, density normally decreases with age. Table 6 indicates for different species what is considered the maximum distance between trees that will result in the formation of satisfactory

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FIGURE 21.—Dense stand in which the stems are cleaning themselves naturally. This is the way long, clear trunks are formed. Note the dense mat of litter and the absence of grass.

stands. Greater density is desirable up to a point where competition will retard growth.

TABLE 6.—*Maximum spacing in southwestern stands to produce trees of desirable form*

Height of tree	Ponderosa pine	Douglas fir	Engelmann spruce	Height of tree	Ponderosa pine	Douglas fir	Engelmann spruce
	Feet	*Feet*	*Feet*		*Feet*	*Feet*	*Feet*
Below ½ foot	2	1	1	7 to 12 feet	6	5	4
½ to 1 foot	3	2	2	13 to 20 feet	7	6	5
1 to 3 feet	4	3	3	21 to 30 feet	8	7	6
4 to 6 feet	5	4	4				

[16] It is a matter of common observation in the Southwest that old gullies in young pine thickets are being sealed by needle litter. These gullies evidently were formed during periods of overgrazing when the pines were too small to interfere with the passage of livestock or to build up a mat of needles. In more recent years suppression of herbaceous vegetation has rendered the areas unattractive to stock, and at the same time the needle cover has increased in depth, partly because of less trampling and partly because the annual fall of needles increases as the trees grow larger.

Overdense stands are the exception, taking the region as a whole, but they do constitute a problem in some localities. In the Black Hills, young stands of ponderosa pine are commonly so crowded that growth stagnates. Even on the Colorado Plateau where the problem is usually one of deficient stocking, ponderosa pine sapling stands are sometimes so dense that the stems become too slender to support the crowns. The most serious condition is found in spruce, because of the greater persistence of individuals in subnormal state and the consequent prolongation of the struggle for supremacy.

On an experimental plot of 40-year-old ponderosa pine on the Prescott National Forest in Arizona, thinning has increased the average diameter growth of the remaining trees by 0.2 inch in all diameter classes during a period of 5 years. This was accomplished by removing the underdeveloped, defective, or misshapen trees. In this instance the wood removed was sold for poles and fuel, netting a small revenue. Except in the Black Hills, however, there is usually no market for small stems and the cost of thinnings is an outright expense. To what extent this can be offset by increased rate of growth depends upon a number of factors, including the price of labor, the rate of growth attainable, and the value of stumpage when the stand is cut.

Ordinarily, the stand left on cut-over areas will be made up of trees of many ages, from the seedling stage up to mature seed trees. If the cutting has been properly executed this residual stand will have been improved by removal of diseased, defective, misshapen, and crowded trees. In past national-forest practice such removals have been limited to stems of merchantable size. Obviously, this limitation has been a silvicultural handicap. Legislation enacted in 1930, known as the Knutson-Vandenburg Act, permits utilizing receipts from the sale of timber on Federal lands for planting or removing undesirable trees in order to improve the future stand of timber on the cutting area. The removal of mistletoe-infected and other diseased trees, release cuttings, and the thinning of overdense young stands may be done under this act, within certain fiscal limitations.

The Emergency Conservation Work Act (Mar. 31, 1933) and the National Industrial Recovery Act (June 16, 1933) furnished unprecedented opportunities for improvement of young timber stands. Not only have extensive areas been thinned and pruned, but the concentrated thought of many foresters engaged in this work has led to a clearer conception of its purpose, possibilities, and limitations.

At the outset it was recognized that costs should be reasonably commensurate with expected returns. In view of uncertainties in regard to the effect on yield and still more as to future timber values, no attempt has been made to fix a definite cost limitation. Actual costs on some 20,000 acres in the southwestern region in 1933 varied greatly, but in the main were around $6 per acre, with a trend toward lower levels.

In 1934 costs were further reduced by limiting cutting to the release of so-called "crop trees" or those which may be expected to figure in the final crop, and the removal of diseased and "wolf trees." Since the number of trees which reach maturity in one rotation seldom exceeds 40 per acre, it has been estimated that 80 crop trees would provide an ample margin for mortality on average pine sites. On Douglas fir, Engelmann spruce, and the better pine sites, more than 80 trees would probably be advantageous. Only crop trees are pruned.

In releasing crop trees, the primary purpose is to give them enough growing space to insure their dominance. It is not considered desirable to thin so heavily as to prevent future crowding because this would encourage ground vegetation and stimulate coarse limb growth. In order to maintain a rapid rate of growth, the crop trees should be favored by periodic removal of competing trees.

To what extent results will warrant such practice cannot be stated at the present time. Plots have been established on which permanent records will be maintained with a view toward answering this and many other questions.

SUSTAINED YIELD

Directly associated with the growing of full timber crops are orderly harvesting and marketing. The forests within a geographic unit, and as far as possible within each community, should generally be so managed that timber yields from year to year will be kept at a constant or rising level. Such a sustained yield lends stability to the forest organization, to the timber market, and to local industry. Under this principle the annual cut may vary with market conditions, but the cut during a period of years must be on a basis in harmony with the yield or permanent productive capacity of the forest.

Sustained yield is a vital economic factor in communities dependent in large part upon forest industries. A lumber manufacturing plant employing 100 or more men is an important business asset to any small town, and if for any reason such a plant must cease operations, even temporarily, the community suffers. Market depressions may necessitate temporary shut-downs, but in a well-regulated forest there should never be a shut-down for want of raw material. There is no greater tragedy in American industry than the familiar one of towns built up on a thriving lumber industry and subsequently abandoned when the last log went through the mill.

An obvious requisite for sustained yield is a proper gradation of age classes. Theoretically, the age classes within a unit of management should be as many as the years in the rotation. In practice, however, it is customary to group trees by 20-year age classes. As has been pointed out, a characteristic arrangement of trees in the ponderosa pine forests, especially on the Colorado Plateau, is in even-aged groups, varying in size but usually between one-tenth and one-half acre. The oldest age classes are represented by remnants in the form of scattered, overmature, dead, or dying trees, usually more than 300 years old. A somewhat younger but still overmature class will be found in groups still intact but disintegrating. Most of the mature timber is in even-aged groups between 200 and 250 years old. Distinction between mature and overmature or very old classes is possible from the appearance of the crown, the overmature class usually showing marked signs of decline. A class of blackjacks about 150 years old occurs in well-defined groups in practically all ponderosa pine forests in the Southwest. Younger age classes represented by large poles, small poles, and saplings, also occur more or less abundantly.

ROTATIONS AND CUTTING CYCLES

Management plans contemplate a saw-timber rotation, or profitable growth limit, for ponderosa pine of 150 to 200 years, depending upon locality and site quality. On the better sites a rotation of about 150 years will produce the maximum annual yield in volume, but, considering quality as well as quantity of yield, a 200-year rotation may prove more profitable. This depends in large measure upon what future markets are going to demand. On some of the poorer sites there are indications that the soil is not capable of carrying well-stocked stands to maturity. Growth is rapid up to a certain age, and then, probably in consequence of prolonged drought and bark-beetle attacks, the trees die in large patches. On such areas a shorter rotation may become necessary. The cutting cycle, too, will be influenced by local conditions and by future market demands. Present indications point to three cutting cycles of about 60 years each. In the Black Hills, present plans call for a rotation of 140 years and four cutting cycles of 35 years each. Although Douglas fir and Engelmann spruce in the Southwest will produce greater volumes than ponderosa pine in a given time, it is uncertain whether they can be handled on shorter rotations because the greater density of the stands makes for smaller diameters. This is especially true of spruce.

From a silvicultural standpoint short cutting cycles will prove most efficient because they tend to relieve competition and also make it possible to salvage a large amount of material which would otherwise be lost. Where extensive areas await the first cutting, a light first cut, to be followed by a second cut in a period less than the regular cutting cycle, would hasten the removal of overmature timber, encourage advance reproduction, and place virgin stands in a better silvicultural condition generally. As pointed out in the early part of this bulletin, however, logging operations call for a certain minimum volume of timber per acre in order to justify overhead expenses such as railways and truck roads. It is probable that in the more accessible localities the cutting cycles will be relatively short and considerable quantities of dead and dying timber will be removed between the regular cuttings.

In ponderosa pine stands in the Southwest that have been logged or are now being logged for the first time, the next cut probably will consist largely of trees 200 years old or older, including the present blackjacks, intermediates, and the surviving mature yellow pines left for seed. The third cut will be made up largely of the present pole stands down to about 60 years of age and such older trees as may be reserved in the second cutting. The volume available will be more or less problematical because on many areas there is a dearth of trees in the lower age classes.

The solid-line graph in figure 22 represents a desirable distribution of age classes in a cut-over stand. As is to be expected, the number of trees of the larger diameters has been reduced by logging. Middle diameters ranging from 14 to 22 inches are well represented, and below about 11 inches there is a sharp rise, indicating that reproduction has been going on during the past 75 years. A great preponderance of numbers in the lower diameter classes is necessary both in order to provide the much-desired dense stocking in youth and in order to offset the normal high mortality in young stands.

The broken-line graph represents the very undesirable actual condition in many instances. There is a preponderance of diameters over 16 inches, which means a good second cut, but the deficiency in diameters below 11 inches augurs ill for the third cut.

LOGGING

Although a full compliance with the minimum measures already prescribed for preventing excessive damage to young growth and reserved trees will fulfill the requirements under intensive management, such compliance is impossible without close supervision on the part of forest officers and whole-hearted cooperation on the part of operators and their employees. As forest management becomes more intensive and utilization more complete, more refinements in logging practice can be put into effect than seem practical now. If such refinements greatly increase the cost of logging, however, the

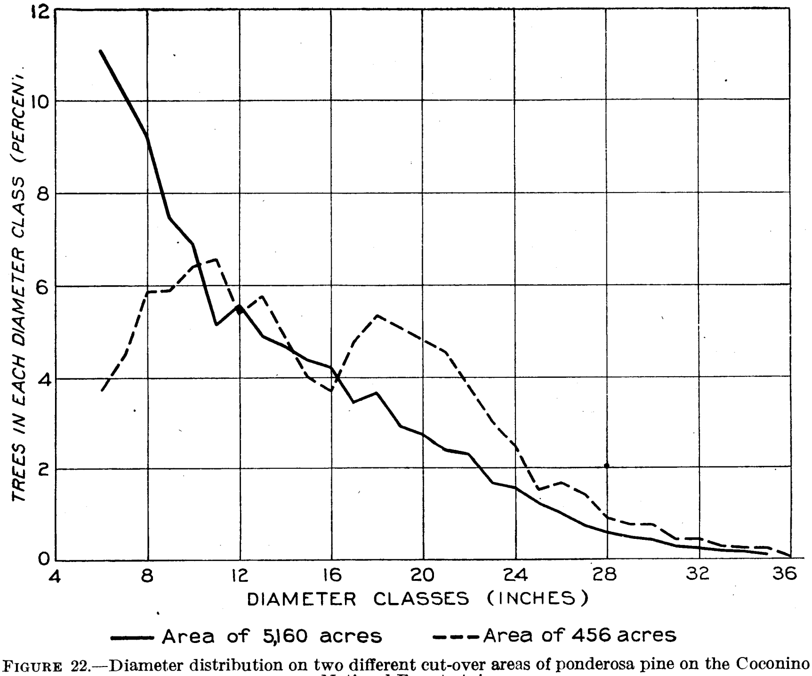

FIGURE 22.—Diameter distribution on two different cut-over areas of ponderosa pine on the Coconino National Forest, Ariz.

extent to which they can be practiced will depend upon timber values.

Opportunities for decreasing logging damage are to be found in both felling and skidding operations. Where the timber occurs in groups the present practice is to fall the trees out, away from the center of the group, into the openings where advance reproduction is at its best. Usually there is little or no reproduction under and for 20 to 40 feet around the tree groups, and therefore this would be the ideal place to fall the trees if it could be done. Not only would damage decrease, but the cost of brush disposal would also decrease. If reproduction is dense, and if the trees are not felled too close together, the thinning effect may be beneficial. On the whole, however, considerable damage usually results from felling trees into young growth, and this increases with the size of the young trees. Skidding operations increase the toll. The damage by this cause is usually underestimated because sufficient weight is not given to bruising of stems and damage to roots by the cutting and packing effect of wheels.

Much can be accomplished by educating loggers to appreciate the value of young trees and the consequences of soil abuse; but the ultimate solution lies in careful planning and direction by forest officers.

Far-reaching benefit can be realized by increasing the efficiency of the logging operation itself. Lowered logging costs and better utilization would make possible silvicultural measures which are not practical now because of the narrow margin between cost of production and selling price. Added transportation facilities through the development of forest roads promise to be an important factor. Another is the stabilizing influence of continuous operation under sustained yield. More silviculture in logging will result in heavier yields per acre and better lumber grades, which will in turn be reflected in lower logging costs.

SLASH DISPOSAL

Slash disposal as a minimum measure for maintaining productive land was discussed wholly with regard to fire protection. Where protection is a first requisite, intensive forestry, which aims at higher standards of production, will on the whole call for even more use of piling and burning. On the other hand, it may be laid down as a general rule for the ponderosa pine type that piling and burning of slash beyond the requirements for fire protection is seldom warranted. Also, more complete utilization in the future should decrease the amount of slash to be disposed of. If the limb wood above a diameter of 2 inches could be utilized, the slash problem would be greatly simplified. Intensive forestry presupposes such control of grazing that the leaving of slash is not warranted as a protection from livestock.

Wherever the soil is deeply covered by litter, and in dense cover of tall grasses, natural reproduction is aided by burning slash. This condition is quite common in the Douglas fir and Engelmann spruce types. Here, however, it becomes necessary to weigh the benefits in favor of young seedlings against the damage to older trees by fire. Often the saplings and young trees are so dense that brush piles cannot be burned without doing excessive damage, and since the fire risk is usually low it may be better to leave the slash and rely entirely on fire protection. The same situation is sometimes encountered in the ponderosa pine type, but here it is usually possible to burn brush piles without excessive damage. Where advance reproduction of ponderosa pine is present, it is exceedingly desirable as a protective measure to burn the brush unless the fire risk is low. In the Black Hills, where advance reproduction occurs almost invariably, piling and burning is standard practice.

As has already been pointed out, slash applied in moderate density distinctly favors reproduction of ponderosa pine on bare soils subject to severe desiccation. Overgrazed clay flats, common on the Colorado Plateau, are a typical example of sites on which slash should be scattered for soil protection. This should be done also on the more or less bare cobblestone areas where the surface soil has been washed away. It is standard practice in the national forests throughout the region, including the Black Hills, to scatter slash on all sites subject to severe erosion and to throw large quantities into unused roads and in gullies.

It is evident from the foregoing discussion that the slash-disposal problem is exceedingly complex. Where the situation demands great caution, the protective measures of slash disposal described on page 40 should be followed. Because of the varying conditions encountered it is seldom possible to formulate rules that can be applied uniformly to a cutting area. The forest officer in charge of a timber sale should understand the principles of slash disposal and should study each area carefully in order to apply the right method on every individual spot. This flexible system is being practiced on the national forests in the Southwest under what is termed "diversified slash disposal."

GRAZING

Past grazing damage to forest reproduction in the Southwest, together with some of the factors involved and remedies applied, has already been discussed in considerable detail. Briefly stated, grazing was for many years the dominant controllable factor in the failure of reproduction on extensive areas; but as a result of improved range management, involving large reductions in and better distribution of stock and shortening of the grazing season, serious damage has to a large extent disappeared. Relief from grazing damage has put new hope into silviculture. Where the lessons in grazing learned from past experience are applied, pine forests can now be cut with assurance that under proper silvicultural and protective measures the cut-over land will restock naturally. Notwithstanding this favorable turn, enough damage persists to show that grazing is still a factor to be reckoned with, and that it calls for special attention in a program that contemplates growing full timber crops.

Good range management should be the main reliance of the silviculturist for prevention of damage by livestock, but he should not depend on it absolutely, because many factors still imperfectly understood influence the feeding habits of livestock. Moreover, it is too much to expect that range management will be perfect where a single ranger is responsible for all administrative activities on many thousands of acres. Cut-over areas should receive special supplemental attention. Even though advance reproduction may have been good before cutting, unstocked areas of considerable size will appear after cutting, and there will be a tendency for livestock to concentrate in these areas.

Because of the susceptibility of very young seedlings to complete eradication, they should be guarded with great vigilance. If, as sometimes happens, 20,000 or more seedlings per acre appear at one time, the landowner should realize that he is confronted by an opportunity which may not be repeated in several decades. For reasons not fully understood, seedlings less than 2 years old have suffered very little since 1926, even on areas where older seedlings show damage. Lighter stocking affords a partial but not complete explanation of this situation; it is possible that the older seedlings now fairly abundant in most places are browsed in preference to very small seedlings. But until the true explanation is known, it should not be taken for granted that such great losses as were experienced in 1919, 1920, and 1921 cannot be repeated. The surest way to detect damage to small seedlings is to lay out a number of plots and make counts of seedlings about once a month through the grazing season. If at any time as many as 5 percent of the seedlings on 10 percent of the total area are killed or severely injured, the situation calls for prompt action.

After the seedlings are 2 years old they are less likely to be killed unless browsed repeatedly. Although damage to this class of seedlings is not to be ignored, a reasonable amount may be tolerated. Where the line should be drawn depends upon a number of circumstances, such as number of seedlings on the ground and the need for relatively heavy grazing in order to check competing vegetation. As an average figure, 5 percent damaged each year on 10 percent of the total area is not excessive.

The possible benefits to forest reproduction by grazing should be weighed against seedling damage. Tall, dense grasses and weeds offer severe competition to young seedlings for light and moisture. This is very evident on areas occupied by Arizona fescue (fig. 12). On stump patches almost any kind of vegetation will, if undisturbed, crowd out pine seedlings unless the seedlings become established first. On the other hand, seedlings which once gain possession of stump patches make the most rapid growth observed anywhere (fig. 23). On bunch-grass lands and on stump patches in bunch grass or elsewhere, grazing should be rather heavy until a good seed crop germinates, and should then be restricted in order to avoid seedling damage. The splendid stand of 1919 seedlings on most of the Colorado Plateau undoubtedly was favored by the heavy grazing of preceding years. If the substantial stock reductions made after 1924 had been made in 1920, the 1919 seedling crop would undoubtedly have been much better generally than it is. Substantially this method of control was successfully applied on small areas in 1914–15 and again in 1919–20 (fig. 24).

If for any reason range management fails to bring about adequate and timely control of damage to forest reproduction, an effective remedy is available in temporary or seasonal exclusion of stock from the areas affected. Leader browsing can be practically stopped by keeping stock off the range through June and early July until the summer rains begin. Needle browsing can be greatly decreased by removing the stock not later than September 30. Both of these measures presuppose conservative grazing and proper handling of stock. If young seedlings are being killed in excessive numbers the situation calls for emergency measures; stock should be excluded until the seedlings are 2 years old, and after that seasonal exclusion should be practiced.

Forest grazing in the Southwest should be regarded more as a silvicultural measure than as the utilization of a forage crop. When young seedlings require special protection, temporary sacrifice of the forage crop is justified. When reproduction can be aided by temporary heavy grazing, this too is justified, provided that precaution be taken against excessive soil deterioration. Objections to both measures may be raised on the ground that they interfere with grazing administration and with the stock industry. This need not be so if adequate foresight is exercised by forest administrators. Provisions should be made, by water development and other improvements, for moving stock from areas requiring light grazing to those requiring

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FIGURE 23.—Effect of grazing on reproduction in stump patches (the spaces immediately around stumps): *A*, No grazing; no reproduction 20 years after cutting; dense bunch grass has taken possession. The groups of seedlings in the distance have come up where grass is of only moderate luxuriance; *B*, extreme overgrazing; nearly all seedlings destroyed; *C*, close grazing, but the seedlings, 6 years old, have escaped serious damage. Seedlings of the same age are abundant but much smaller outside of the stump patch.

heavy grazing for silvicultural reasons. Every national forest should have reserve range for use in emergencies. After an orderly system of forest management is once in effect, the areas to be restocked at any one time will not be large enough to affect more than 2 or 3 grazing allotments in a national forest. It must be expected, however,

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FIGURE 24.—*A*, Good reproduction of ponderosa pine under controlled grazing. Fence built in 1915 following good germination in 1914; moderate grazing by cattle and horses allowed inside pasture; outside (foreground), heavy overgrazing killed most of the seedlings and damaged the others; under lighter grazing since 1929 the surviving seedlings have begun to grow. *B*, Good reproduction under continuous grazing. Germination in 1919; many seedlings were killed in 1920, but stock was reduced in 1921 and again in 1925; reproduction has taken place entirely after cutting.

that the establishment of dense sapling and pole thickets will decrease forage production. Unless this is anticipated and provided for, a time will come when the number of livestock on areas of second growth will exceed the carrying capacity, to the detriment of associated areas in the process of regeneration.

CONTROL OF INSECTS, BIRDS, MAMMALS, AND DISEASES

Intensive forestry is not possible without adequate control of animal life and pathological agencies which may adversely affect the forest. Since control measures in these fields are of a highly specialized nature, it is not the purpose to discuss them here beyond pointing out some of the conditions under which control may be necessary. It is the policy of the Forest Service in dealing with these problems to enlist the cooperation of the Bureaus of Entomology and Plant Quarantine, Biological Survey, and Plant Industry, within their respective provinces.

INSECTS

Such insect pests as the spruce budworm, hemlock looper, and tip moth, though their activity is responsible for much damage, have not been successfully controlled on a large scale. Baumhofer [17] has employed the parasite *Campoplex frustranae* in the control of *Rhyacionia frustrana bushnelli*, a western form of the Nantucket tip moth, in ponderosa pine plantations at Halsey, Nebr.; but, unfortunately, this parasite has not proven effective against the Southwestern tip moth, *R. neomexicana* Dyar.

Peeling of the infested trees is sufficient to check the attacks of the Black Hills beetle and some other bark beetles, but burning the bark is practiced for such forms as *D. barberi* (Hopk.) and *D. convexifrons* (Hopk.). It has been pointed out by the Bureau of Entomology and Plant Quarantine that in a going logging operation bark beetles are in large measure controlled automatically, because felled trees become trap trees and the larvae are destroyed when the logs go through the mill. If for any reason the logging operation stops, an abnormal amount of damage may result. In localities subject to *Ips* attacks, great care must often be taken in the pine type to burn slash and peel the bark from large material left in the woods after logging. A common error is to clear rights-of-way for roads and building sites without adequate precautions against *Ips;* the consequence is often the killing of young trees highly prized for scenic purposes. Fortunately, the activity of *Ips* is rather localized. It appears to be worst in the lower edge of the pine type and following dry years.

BIRDS AND MAMMALS

All evidence at hand indicates that control of seed-eating rodents is desirable, not to say necessary, under certain conditions. On areas which must be restocked after cutting, reduction in numbers of mice, chipmunks, and ground squirrels would undoubtedly hasten the process of restocking. In artificial reforestation by direct seeding, control of rodents would be one of the first steps in the program. Poisoned grain prepared by the Bureau of Biological Survey has been used to reduce the numbers of mice and chipmunks.

Birds, as a class, are to be regarded as beneficial through their activities against insects and rodents and in disseminating tree seeds. Although instances of birds injuring young conifer seedlings are not lacking, such damage is undoubtedly outweighed by the benefits of insect control. It is well known that most species of hawks and owls are active in killing rodents.

[17] The results of this work by L. G. Baumhofer have not yet been published.

Wherever the porcupine is present in large numbers, control measures are essential to the production of full timber crops. The Bureau of Biological Survey (*4*) has developed effective control methods, including use of a poison bait, consisting essentially of strychnine and salt, that is being used with good results on the Coconino and Tusayan National Forests of Arizona. Control measures are also urgently needed in northern New Mexico, Colorado, and the Black Hills.

The idea that large forest areas can be set aside and maintained permanently as game sanctuaries, destroying predatory animals and permitting the game to increase indefinitely, is no longer tenable. Stocking of a range with deer, antelope, and elk must be as carefully adjusted to the carrying capacity of the range as is the stocking with domestic animals. Forest areas which are largely devoid of shrubby growth should be lightly stocked with big game because in the absence of this class of forage they are likely to attack young conifer trees. As soon as the game has increased to nearly the carrying capacity of the range, measures should be taken to insure removal of the normal increase.

On areas set aside for the preservation of native flora and fauna, it would be a mistake to exterminate the predatory animals that are nature's safeguard against overstocking with deer and rodents. Moderate control of predatory animals may be necessary but, without a check on the increase of grazing and browsing animals, the consequent disturbance of natural conditions may be greater than under the usual forms of industrial exploitation.

Any attempt to discuss animal life in relation to the forest is handicapped by a lack of specific information as to the habits of different species. No control operations should be undertaken without carefully weighing beneficial against harmful activities. It is important to consider not only the direct and obvious effects, usually detrimental, but also the indirect effects, such as that of one animal preying upon another, or the effects upon soil and competing vegetation. Even in the case of seed-eating rodents, it is possible that some species are a factor in keeping insects in check. Further studies are needed of the life histories of all animals of the forest, including mammals, birds, and insects.

DISEASES

Of the pathological agencies affecting the forests in this region, those causing decay of wood and the parasite mistletoe are most susceptible of control by means at the disposal of forest management.

There is no known way of checking wood-rotting organisms in a living tree and therefore control measures must take the form of prevention. Heart rots usually gain entrance through dead limbs, so the early natural pruning obtainable in densely stocked young stands should exert a favorable influence. Prevention of fruiting or spore formation should also prove effective. The most important wood-rotting fungus, namely western red rot (*Polyporus ellisianus*) continues to function and fruit after the tree has been felled. However, it generally fruits only on the under side of logs in contact with the ground, and then only if the bark remains on the wood. Effective remedies against fruiting are to peel all logs or limbs over

6 inches in diameter, char them in brush burning, or keep them off the ground. The last measure can often be effected by limbing in such manner as to leave the bole supported by "prong horns" or stubs of branches.

Unlike heart rots, mistletoe ceases to be a menace when the tree dies. Aside from limited possibilities in removing infected branches, the only known means of controlling mistletoe is to cut the infected trees (*6*). Foresters in the Southwest have been more or less uncertain as to how far it is advisable to carry this measure. In many instances complete eradication means almost clear cutting. In such cases, the old trees, or yellow pines, should be carefully examined for specimens free of mistletoe to be left for seed trees. Young trees free of mistletoe are, of course, also desirable. The fact that a tree exposed to mistletoe has escaped infection indicates that it may be immune, and this suggests the possibility of developing a resistant strain (*2*). If as many as 3 such trees per acre of more than 20 inches in diameter can be left, the removal of all mistletoe-infected trees, including saplings and seedlings, is justified silviculturally. Experience has shown that fairly good reproduction can be obtained with large seed trees in numbers averaging 2.5 per acre. How much farther this reduction might go is problematical. If reproduction is not adequate, planting may become a necessity.

The best solution of the mistletoe problem is to withhold cutting until good advance reproduction is obtained, and then cut everything bearing a vestige of the parasite. The logging operation should be followed by clean-up surveys in order to remove any trees or branches on which mistletoe may have made its appearance. Obviously, the felling of unmerchantable trees is going to cost money. How much of an expenditure is justifiable depends upon many circumstances. Where the cost of thorough eradication is less than the stumpage value of the timber, the expense would seem to be warranted if a fairly good stand of reproduction can be obtained.

It must be admitted, however, that no one knows whether absolute eradication of mistletoe is necessary, and whether a stand once freed of the pest can be kept clean without excessive outlay for control operations.

How rapidly a large area will be reinfected is not known. Birds, squirrels, and porcupines undoubtedly are potent factors in disseminating mistletoe seeds. The whole problem requires further investigation.

Much of what has been said about the difficulties of mistletoe control applies to other pathological organisms. Control operations are always interwoven with economic questions and biological and ecological relationships. The necessity for research suggests itself at every turn. Not only must the life histories of disease-producing organisms be known but their action upon and response to plants, animals, and physical factors should be better known. Research of this character should be supplemented by experimental control operations on designated areas to be kept under permanent record.

PROBABLE YIELDS UNDER GOOD MANAGEMENT

Relatively little attention has been given to determining possible yields in normal or fully stocked stands in this region. This is because such stands in the mature stage are found only on very small areas and it is not known to what extent they represent a goal possible of attainment on a large scale. As has been stated previously, mature stands of ponderosa pine seldom bear as much as half the volume that the soil can support. This is evident from the large proportion of land within virgin forests that is either unstocked or bears only seedling or sapling growth. It is difficult to find mature, even-aged, fully stocked pine in blocks of as much as an acre. Where such blocks are found on good sites in the Southwest the total volume is usually from 20,000 to 30,000 feet board measure at 150 years, and up to 40,000 feet at 200 years. There is little doubt that yields of this magnitude could be produced on the better sites if it were possible to maintain full stocking throughout a rotation. Still higher yields are theoretically possible in the Douglas fir and Engelmann spruce types.

It may be assumed that under intensive management the stocking and the yields of virgin stands can be greatly improved; but how nearly they can be made to approach 100-percent efficiency is problematical. Fire and overgrazing, the two greatest obstacles to natural reproduction in the past, will probably be controlled in the future, but present indications are that even if these factors were entirely eliminated complete restocking on all the land could not be expected. Moreover, complete stocking in early stages does not insure full crops unless the stocking can be maintained. Insects and disease undoubtedly have operated to reduce the stocking of established young stands, or to hamper their growth. Science may come to the rescue, but control measures cost money. Then there are the droughts, which occupy such a prominent place in the traditions of the Southwest. Granting that only indirect proof exists of droughts severe enough to exterminate or cause the migration of former civilizations, accounts within historic times give a hint of the dangers to which a forest is exposed during a rotation of 150 to 200 years. Though the possibilities of silviculture should not be minimized, it is only fair to recognize its limitations. Making due allowance on both sides, it is safe to assume that present average yields can be increased by 50 percent. Thus, whereas mature virgin forests of ponderosa pine in good state of preservation now yield 10,000 to 20,000 feet board measure per acre at an age of 200 or more years, it is reasonable to expect that under good management the yield can be increased to 15,000 to 30,000, depending on site quality.

Although yield during a rotation is the usual criterion of producing capacity, the forester who is managing many-aged stands is more directly concerned with yield during the cutting cycle. He wants to know how often his forest can be cut over and how much can be removed in each cut. In the Southwest, present predictions of yield usually do not extend beyond the second cut.

Growth studies have been made on cut-over areas in the Southwest by means of 5-year measurements on sample plots over periods of 15 or 20 years.[18] Table 7 gives the volume of growing stock, annual increment, and annual mortality on several plots cut by different methods on the Coconino and Kaibab National Forests. So far as increment is concerned, the main difference between these plots is in the volume of growing stock left after cutting. Mortality is also an important factor. The scattered seed-tree plot has the lowest

[18] Measurements and compilations in tables 7, 9, 10, and 11 by Herman Krauch.

volume of growing stock and next to the highest mortality, a combination which is reflected in both actual and relative increment. The shelter-wood cutting, which, owing to the character of the original stand, is virtually only a light group-selection cutting, gives the highest yield in board feet per acre, but a lower percentage yield than the standard group-selection cutting. The high residual volume and low net increment percentage associated with a moderate rate of mortality indicate that the trees may be too closely spaced for rapid growth.

TABLE 7.—*Increment and mortality of ponderosa pine in relation to method of cutting and volume of growing stock, Coconino and Kaibab National Forests*

Plot and method of cutting	Area of plot	Length of record	Volume [1] per acre left	Net annual increment per acre [2]		Annual mortality per acre	
	Acres	*Years*	*Ft. b. m.*	*Ft. b. m.*	*Percent*	*Ft. b. m.*	*Percent*
S3, group selection	456	20	3, 520	91	2. 59	20	0. 57
S4, group selection	304	20	2, 328	67	2. 88	8	. 34
S5-I, group selection	139	15	2, 846	79	2. 78	18	. 63
S5-II, scattered seed tree	152	15	1, 873	30	1. 60	22	1. 17
S5-III, shelter wood	112	15	4, 510	93	2. 06	29	. 64

[1] All board-foot volumes are according to the Scribner log scale including only trees 12 inches or more d. b. h.

[2] Net increment is gross increment reduced by the amount of annual mortality. With intensive management most of the dying trees 12 inches or more in diameter would be salvaged, so that the realizable increment would approach the gross increment.

Table 8, based on extensive cutting areas on the Coconino, indicates that the sample plots in tables 7 and 10 have a higher volume but a lower number of trees per acre than the average cut-over stand. The excess in numbers on the larger areas is chiefly in the diameters below 12 inches. This indicates that the extensive areas are probably adding less board-foot volume than the sample plots at the present time but that after 40 or 50 years they may yield more than the sample plots.

TABLE 8.—*Number of ponderosa pine trees per acre on cut-over areas, in different diameter classes, Coconino National Forest*

Diameter class (inches)	Oak Creek unit—5,785 acres; 2,038 board feet per acre; cut 1930–31	Mormon Lake unit—3,990 acres; 2,618 board feet per acre; cut 1927–28	Howard Mountain unit—4,930 acres; 2,136 board feet per acre; cut 1912–17
	Number	*Number*	*Number*
4–11	28. 11	[1] 16. 40	18. 37
12–20	3. 18	7. 62	5. 65
21–29	2. 17	3. 11	2. 46
Over 29	. 44	. 28	. 32
Total	33. 90	27. 41	26. 80

[1] 4–7-inch trees omitted.

Strictly comparable data are not available for New Mexico, Colorado, and the Black Hills. It is known, however, that in general the forests in these sections have more trees per acre and smaller ones and that the volumes left after cutting are less than on the Coconino and Tusayan. Thus, in the Black Hills, measurements on 28 sample acres [19] after cutting show 126 trees per acre in the 4- to 11-inch class,

[19] MANAGEMENT PLAN FOR THE CUSTER WORKING CIRCLE. Unpublished.

14 in the 12- to 20-inch class, and none over 20 inches. The average volume per acre on extensive cut-over areas is 1,569 board feet and the calculated annual increment 81.6 board feet. Thus, the Black Hills National Forest with a lower volume of growing stock yields about the same annual increment as the Coconino and Tusayan Forests. Somewhat lower yields are to be expected in New Mexico and probably in Colorado.

Rate of diameter growth is important not only as an index of volume production but also as an index of merchantability. Although little is known about future market demands, it is probably safe to assume that saw logs of fairly large diameter will always be at a premium. In silvicultural cuttings in the Southwest, immature trees of different diameters increase in diameter at nearly a constant rate (table 9). This is because the larger trees usually have crowns and roots in proportion to their basal area. The older trees (yellow pines), however, grow more slowly in the larger diameters. In the Black Hills, the rate of growth is much slower generally, and the large trees grow less rapidly in diameter than the smaller ones. Thus, trees in the 4- to 11-inch class grow 0.106 inch, and in the 12- to 20-inch class, 0.086 inch per year, as compared with 0.169 and 0.181 inch for blackjack in group-selection and shelter-wood cuttings on the Coconino. The lower rate in the Black Hills is obviously due to the greater density.

TABLE 9.—*Diameter growth of ponderosa pine in relation to age and size of trees, Coconino and Kaibab National Forests* [1]

MEAN ANNUAL DIAMETER GROWTH

Plot	Blackjacks, less than 180 years			Yellow pine, 180 years and more		
	4–11 inches d. b. h.	12–20 inches d. b. h.	21–30 inches d. b. h.	12–20 inches d. b. h.	21–30 inches d. b. h.	31–40 inches d. b. h.
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
S1, S2, S3	0.142	0.150	0.146	----------	----------	----------
S5–I	.194	.202	.171	0.148	0.137	0.129
S5–II	.273	.248	.240	.200	.164	.160
S5–III	.171	.191	.194	.148	.135	.131

TREES MEASURED ON PLOTS

Plot						
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
S1, S2, S3	392	434	101	----------	----------	----------
S5–I	1,284	1,133	193	77	187	22
S5–II	619	220	120	27	122	49
S5–III	1,022	899	121	104	305	53

[1] Records for plots S1, S2, and S3 cover a period of 20 years (1909–29); records for plots S5–I, II, and III cover a period of 10 years (1913–23).

If all the trees could be expected to survive it would be a simple matter to calculate yield from rate-of-diameter growth applied to a stand table. This is sometimes done. That such calculations would be greatly in error is indicated by the mortality figures compiled by Krauch (*8*) and given in tables 7 and 10. Table 10 also shows that the rate of mortality is highest in the diameter classes above 30 inches (*7*). As shown in table 11 the causes of mortality vary somewhat for different plots, mistletoe and wind being the main factors when measured in numbers; on the basis of volume lightning assumes greater importance than here indicated because of its tendency to strike large trees. Lightning and windfall are the main factors contributing to the high mortality of sample plot S5–II. It has been pointed out by Krauch (7) that lightning strikes about the same number of tall trees per acre regardless of the total number present; thus, the percentage of lightning loss on an area bearing only 2 tall trees per acre is likely to be twice as high as on an area bearing 4 tall trees per acre.

TABLE 10.—*Annual mortality of ponderosa pine by diameter classes in percentage of total number of trees in each class*

Plot [1]	Number of trees per acre and annual loss, by diameter class									
	4–11 inches		12–20 inches		21–30 inches		Over 30 inches		All classes	
	Trees	Loss	Trees	Loss	Trees	Loss	Trees	Loss	Trees	Loss
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
S3	6.4	0.70	7.7	0.36	3.7	0.45	0.3	1.32	18.1	0.57
S4	5.9	.23	6.8	.23	2.3	.40	.3	.46	15.3	.34
S5–I	10.5	.75	9.0	.29	2.9	.49	.2	1.84	22.6	.63
S5–II	4.7	.60	1.8	.55	1.8	.71	.4	1.46	8.7	1.17
S5–III	10.5	.73	9.2	.29	4.0	.53	.6	1.01	24.3	.64

[1] Area of plots and length of record are as given in table 7.

TABLE 11.—*Mean annual mortality of ponderosa pine by causes*

Cause of death	Plot S3	Plot S4	Plot S5–I	Plot S5–II	Plot S5–III
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Suppression	0.029	0.016	0.054	0.032	0.018
Mistletoe	.282	.000	.262	.182	.242
Wind	.077	.050	.101	.200	.137
Lightning	.041	.022	.026	.084	.029
Insects	.035	.046	.030	.021	.018
Unclassified	.049	.052	.073	.136	.086
Total	.513	[1] .259	.546	.655	.530
	Number	*Number*	*Number*	*Number*	*Number*
Trees per acre	18.1	15.3	22.6	8.7	24.3
Total live trees on plot	8,248	4,651	3,107	1,273	2,666
Total dead trees on plot	847	241	254	125	212

[1] Includes 0.026 cut in trespass and 0.047 killed by fire.

Until sufficient time has elapsed to permit developing a balanced growing stock and until economic conditions are such as to justify more intensive forestry than is being practiced on the national forests, average net increments higher than those which have been indicated, namely, about 80 board feet, cannot be expected generally. Closer utilization would tend to raise this figure, especially in the Southwest where the present minimum diameter is 12 inches d. b. h. On the other hand, it is not known whether the rate of increment established by the end of the first 20 years after cutting can be maintained to the end of the cutting cycle. An important handicap is the fact that much of the earlier cutting left only 1,500 to 2,000 board feet per acre, whereas a growing stock amounting to at least 3,000 board feet per acre is essential to produce a maximum yield. All things considered, an average annual increment of 80 board feet per acre during the first cutting cycle is probably a fair estimate. This means that by the time of the second cut the volume will have increased by between 4,000 and 5,000 board feet per acre in the Southwest, where the cutting cycle is set at about 60 years in present management plans, and by somewhat less than 3,000 board feet in the Black Hills, where a 35-year cutting cycle has been adopted. As has been pointed out, these yields might easily be increased by 50 percent or more under really intensive management, which would generally mean shorter cutting cycles and a larger residual growing stock after each cutting.

COSTS AND RETURNS

The market value of a crop to be harvested 50, 100, or 200 years hence is even more a subject for speculation than yields in volume and quality of wood. Economic conditions may change radically, and no one can definitely predict what the demand for wood products will be 50 years hence. That a market will exist for all wood that can be produced and sold at a reasonable cost is scarcely to be doubted; but whether it will be mainly in the form of cellulose or in the form of saw logs, and what price can be obtained for the raw materials, are matters on which opinion differs. Granting that great progress will be made in the development of processes for converting low-grade material into usable products, it is probable that those processes will be applied mainly in utilizing what is now classed as waste. Information now available provides no valid grounds for believing that the growing of small-sized timber will prove more profitable than the growing of saw logs.

Although it is difficult on account of the many uncertainties to present definite figures on costs and returns, it is nevertheless important to recognize the factors for and against the economic success of timber growing in the region under consideration. One of the most adverse factors is the relatively slow rate of tree growth. To an even greater extent here than in forests which mature more quickly, the accumulation of carrying charges over the long period required to grow a timber crop starting with bare land is likely to exceed the amount that can be realized for the crop. A form of forest management based on clear cutting and restocking by either natural or artificial means is not likely to prove financially profitable, except under especially favorable circumstances, and probably on relatively small areas. Private owners may, however, find it advantageous to retain ownership of cut-over land already stocked with young growth, provided such land constitutes a minor portion of a sustained-yield forest property.

Management of forests in these regions by a clear cutting system is just as undesirable for public as for private forests. In the case of public forests, however, there can be little doubt as to the desirability of holding and protecting areas of established young growth and of planting much of the land in need of restocking. Public forests do not have to meet annual charges for taxes. The young stands and lands needing restocking are mostly integral parts of larger management units which contain mature timber. Maintenance of a forest cover is in many instances necessary in order to safeguard the public interest in soil, water, and recreation, as well as for timber production.

Planting costs from $12 to $20 per acre according to soil and climatic conditions. It is not included in the silvicultural measures recommended in this bulletin because the lands with which we are here concerned are assumed to bear enough seed trees for natural restocking. If supplemental planting should appear necessary in order to obtain full stocking, it should be carefully considered whether the cost is warranted.

Although it is generally desirable, in the long run, to hold expenditures below receipts, this may not be practicable or economically sound where forests are in the early stages of management and development. In such cases current expenditures in excess of receipts may be fully justified in order to insure greater returns in the future. High indirect values in some instances may also warrant expenditures that will not be covered by direct income. The primary costs of forest management will be the annual expenditures for protection and administration, a variable portion of which may be charged against grazing and indirect interests such as water resources, game, and recreation. How large this portion may be should be gaged by the values represented and the benefits obtainable. Planting will play a minor role. Thinnings and improvement cuttings will find a place in silviculture when market conditions are such that the material removed can be sold for enough to pay the cost of removal, or perhaps to a limited extent in connection with emergency work projects.

To maintain a fair balance between current expenditures and receipts calls for a large tract under one management on the sustained-yield plan. Under this plan the timber will be cut from an individual acre only at intervals, but on a large area, such as a national forest or group of national forests, cutting will be going on somewhere all the time and there will be a more or less constant flow of timber receipts from the property as a whole. If over a long period receipts equal or exceed expenditures, the forest is said to be self-supporting or revenue-producing.

When the national forests were created it was predicted that within a few years they would become self-supporting. This prediction has not been realized for the entire national-forest system, partly because most of the timber is still inaccessible to markets, and partly because of heavy expenditures for permanent improvements, such as ranger stations, stock fences, telephone lines, and roads, which should be amortized over a long period. The roads are in many instances built mainly for the benefit of the traveling public, and therefore should not be charged against the cost of forest management. Those forests so situated as to permit exploitation of their timber resources in a degree commensurate with their productive capacity have reached or are rapidly approaching a point where receipts equal expenditures for protection and administration. A notable example is the Harney National Forest in the Black Hills, which during the 5 years prior to 1931 yielded a net revenue, even when the cost of roads was included in expenditures. The Coconino National Forest in Arizona, despite the fact that most of the timber nearest the Santa Fe Railroad was logged off or acquired by private interests in pre-national-forest days, has for many years been self-supporting if the cost of roads is not considered. Enough accessible virgin timber remains in this forest to permit a substantial increase in the rate of cutting during the next half century, and at the end of this period regrowth will maintain the cut indefinitely. A railroad built from the main line of the Santa Fe 100 miles south into the Sitgreaves National Forest in 1918 has put this forest in the same class with the Coconino. In Colorado the San Juan and Montezuma Forests are more than paying the cost of operation, outside of road construction.

As has been pointed out, there are extensive forest areas which, though bearing good stands of timber, are so situated geographically or topographically that their products cannot be marketed. In some instances the transportation problem will be solved in time, but in others the possibilities are very remote. Obviously such lands should occupy a subordinate place in a timber-growing program, and expenditures for protection and administration should be subject to justification on other grounds than those of timber production.

An estimate has been made of the costs and probable returns on a 450,000-acre tract of ponderosa pine on the Sitgreaves National Forest, assuming that it is to be managed primarily for timber production. This timber is practically all accessible for logging, and the growth is better than the average in the Southwest. Timber operations, cutting about 30,000,000 board feet per year, have been in progress since 1920. The annual costs, covering protection, administration of grazing and timber sales, and construction and maintenance of necessary improvements, are estimated at 9.5 cents per acre. Interest on the investment and taxes are not included, since the land is in Government ownership. It should be noted in this connection, however, that 25 percent of the gross receipts from the national forests is required by law to be paid over to the States for the benefit of roads and schools in the counties in which the forests are situated. This has the effect of reducing the forest income by 25 percent. Assuming a net annual increment of 100 board feet per acre at $2 per M board feet on a sustained-yield basis, the gross return from timber sales would be 20 cents per acre, and about 1 cent additional might be obtained from grazing fees. This would leave a net annual return of 11.5 cents per acre (or 6.25 cents after deducting the 25 percent paid to the State). The increment of ponderosa pine on lands of average productivity on national forests in the Southwest probably will not exceed 80 board feet per acre under present standards of management. This would reduce the net income to 7.5 cents per acre (3.25 cents after the 25-percent deduction).

It has been assumed throughout this bulletin that private forestry as a business will not be practiced to any great extent in this region. A primary factor in this assumption is the slow growth of timber. That this alone is not necessarily a prohibiting factor is indicated by the above figures. Where the land and growing stock represent little or no cash investment and cannot readily be converted into cash, as is the case in some instances, a net return of 11.5 cents an acre or even less is reasonable if it can be realized annually, and if taxes do not take a larger share of the income than that represented by the national-forest contribution to roads and schools. It is believed that under especially favorable conditions with respect to quality of land and timber, size of holding, and accessibility to market, forestry has possibilities as a private enterprise in this region. Excepting the Homestake holdings in the Black Hills, however, very few suitable areas of large extent remain in private ownership. The primary requisites for economic success do exist in the national forests and other Government-owned forest lands, and for this reason, along with other advantages in the way of low capital investment and important indirect public benefits, the practice of forestry on public lands is considered economically sound.

SUMMARY

The minimum measures necessary to keep forest land productive, discussed in the first part of this bulletin, aim but little higher than to prevent forest destruction. They are intended to apply to land held by private owners who do not intend to practice forestry as a business enterprise but wish to leave their cut-over lands in such condition that public agencies can acquire them and make them into productive forests without undue expense for reforestation. They include fire protection, involving necessary disposal of logging slash; regulation of cutting so as to leave young trees and a few old trees for seed; prevention of unnecessary logging damage; and prevention of excessive damage to young trees by grazing.

If, however, the owner aims at producing the best timber crops the land will support, the standards are a great deal higher, although possible of attainment in the course of time, and generally practicable for land in public ownership. It is assumed that lands handled temporarily under the first plan will sooner or later be acquired by the State or the Federal Government and placed under the more intensive management provided in the second plan.

Measures necessary to grow full timber crops are fundamentally similar to but more intensive than those outlined under the simpler plan. A wider margin of safety and greater precaution against faulty execution are contemplated. The measures requiring special attention may be summarized as follows:

Management of forests awaiting harvest should aim to bring all of the soil into full production as rapidly as possible. This involves obtaining advance reproduction in all open stands and building up the younger age classes usually deficient in virgin stands.

Cutting regulations should aim, in addition to leaving the needed seed trees, to provide a growing stock of such volume and consisting of such age classes as to permit a series of cuttings at specified intervals on a sustained-yield plan.

Restocking after cutting must be prompt and the young stands should be of such density as to encourage production of high quality as well as maximum volume of timber. Restocking must generally be by natural rather than artificial means because planting is too expensive.

Soil productivity must be maintained. The first step in soil conservation is to encourage absorption of water by maintaining a soil cover. Cutting, logging, and grazing practices should provide adequate safeguards against disturbance of soil cover.

The best development of young stands requires that attention be given to the porcupine, to other rodents, and to insects, as well as to diseases, and especially to mistletoe. The place of thinning and pruning in a silvicultural program will be determined by their influence on costs and returns.

Grazing will probably always be more or less inseparable from forest management in the Southwest. Improved methods of range management, with special reference to numbers of stock, distribution,

and seasons, will go far toward eliminating damage to seedlings. As an additional safeguard, forest managers should be constantly on the alert for grazing damage. It is of great importance to know that until seedlings are 2 years old they may be completely obliterated by severe browsing, whereas after this age, although retarded in growth, they are rarely killed, except where browsing is repeated year after year.

Watershed protection has long been recognized as a primary function of forest management. Good silviculture in striving to maintain a complete cover of trees, seedlings, and leaf-litter automatically tends to check erosion, decrease surface run-off, and increase the flow from underground sources.

Timber growing cannot be generally recommended in this region as an investment for private capital, but it is regarded as a feasible and necessary public enterprise. From a public viewpoint the cost of administration, protection, and management of forest lands is not as a rule chargeable entirely against the timber crop, but is properly shared by other interests such as grazing, watershed protection, and recreation.

The intensity of silvicultural measures should be governed by the productive capacity and accessibility of the land. As a rule, measures calling for a considerable cash outlay will have to be eliminated or confined to good lands so located that their products can be marketed profitably. The expenditures justified must be determined separately for each forest area considered.

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